Laboratory Environment Safety and Health Committee
Cryogenic Safety Subcommittee

MINUTES OF MEETING 05-09

August 24, 2005

Final

Committee Members Present	Committee Members Absent
W. Glenn	R. Alforque
E. Lessard (Chairperson)	S. Kane
P. Mortazavi	M. Rehak
A. Sidi-Yekhlef	K. C. Wu
R. Travis (Secretary)[1]	

Visitors
A. Ackerman

Agenda:
1. NSLS Cryogenic System Review

Minutes of Meeting: Appended on pages 2 through 4.

E. Lessard	**Date**	**J. Tarpinian**	**Date**
LESHC Chairperson		**ESH&Q ALD**	

[1] For quorum purposes LESHC Secretary, R. Travis, was designated as a full Committee member for this meeting.

Chairperson E. Lessard called the ninth meeting in 2005 of the Laboratory Environmental Safety and Health Committee (LESHC) to order on August 24, 2005 at 1:43 p.m.

1. **NSLS Cryogenic System Review:**
   - 1.1. As documented in an addendum to the LESHC 03-05 Minutes (8/4/03), NSLS agreed to perform ODH analyses for dewar transport and temporary storage areas for all experimental activities at their facility in conformance with the ODH Subject Area. This meeting fulfills the LESHC 03-05 requirement.
   - 1.2. E. Lessard invited A. Ackerman of the National Synchrotron Light Source, to present the NSLS Cryogenic Systems to the Committee[2].
   - 1.3. Mr. Ackerman and other attendees made the following points during the course of the presentation and in response to specific Committee questions:
     - 1.3.1. The X17 Wiggler cryogen system in Mechanical Equipment Room A (MER A) and the LN2 filling station at the West Rollup Doors are the focus of this meeting. The remaining cryogenic systems at the NSLS have been previously reviewed by the Committee (e.g., LEGS), or are decommissioned (MER 7 and 8).
     - 1.3.2. The X17 Cryogenic System (located in MER A)
       - 1.3.2.1. Photographs, Plans and Sections of MER A, a Flow Diagram and P&ID were presented to familiarize the Committee with the system.
       - 1.3.2.2. The system includes a 1000 liter LHe dewar, a 40,000 liter LN2 tank (external to MER A), LHe refrigerator/liquefier, compressors, liquid and gaseous helium and nitrogen piping.
       - 1.3.2.3. The LHe dewar buffers changes in the wiggler cooling demand. It is a semi automatic system; dewar level is controlled by a variac level instrument.
       - 1.3.2.4. Some system failure modes require operator attention.
       - 1.3.2.5. Access to MER A is limited to ODH trained personnel, primarily the NSLS Utility Group (for system maintenance and checks).
       - 1.3.2.6. In addition to signage, the area has ODH beacons and audible alarms, oxygen sensors, and an interlocked exhaust fan.
       - 1.3.2.7. The ODH analysis for MER A was reviewed:
         - 1.3.2.7.1. Several system failures of LHe, LN2 and gaseous components are postulated.
         - 1.3.2.7.2. Based on sensors within the room, the initial oxygen concentration was chosen as 21%.
         - 1.3.2.7.3. Certain oxygen sensors do not respond well in the presence of helium. The Committee requested verification that the Gastec sensors are designed for both helium and nitrogen applications. Asher Etkin of C-AD can provide some background on this issue.
         - 1.3.2.7.4. A standby ceiling mounted exhaust fan (non-emergency power) is credited in the calculations.

[2] Mr. Ackerman's presentation, related documentation and these Minutes are posted on the LESHC website: http://www.rhichome.bnl.gov/AGS/Accel/SND/laboratory_environemnt,_safety_and_health_committee.htm.)

1.3.2.7.5. MER A was calculated as an ODH Class 0 area. (Fatality factor of 1.095E-14.)

1.3.2.7.6. The Committee noted that the calculated fatality factor was extremely low. In addition, there were several questions concerning system failure modes (including dewar failure assumptions), the modeling of the exhaust fan system (particularly the fan switch and alarm) and the treatment of multiple piping runs that could not be resolved during the meeting. NSLS was requested to review the Committee input, make any necessary changes and submit the calculation for LESHC review.

1.3.3. The LN2 Filling Station

1.3.3.1. The LN2 Filling Station is a manual filling station located between the two West Rollup Doors. It is used primarily by the NSLS experimenters to fill their dewars.

1.3.3.2. Liquid nitrogen from the 40,000 liter LN2 tank (located outside the building) is supplied via a vacuum jacketed transfer line to the filling station.

1.3.3.3. There is a single oxygen sensor. Upon actuation it will: activate audible and visual alarms, close the supply valve and open one rollup door.

1.3.3.4. One Committee member noted that visual alarms are typically located at about eye level. The placement of the exterior beacon (above the personnel door) appears to be too high. In response to a Committee recommendation (not a requirement), NSLS agreed to evaluate the location of this beacon.

1.3.3.5. The LN2 Filling Station is located in an area with a lot of through traffic. There are no access controls. Training consists of NSLS General User Training and the posted instructions at the Fill Station. Although it is considered ODH 0, no ODH training is required for this area.

1.3.3.6. The ODH analysis for the LN2 Fill Station was reviewed.

1.3.3.6.1. A transfer line leak/rupture or a fill valve failure to close is postulated, with additional alarm, electric power or rollup door failures

1.3.3.6.2. The LN2 Fill Station was calculated as an ODH Class 0 area.

1.3.3.6.3. A cursory Committee review indicated that this calculation might be overly conservative. If it can be reclassified as “ODH Not Applicable”, there will be no training requirements for users or passersby.

1.3.3.6.4. The NSLS has procedures in place to assure testing and maintenance of the LN2 Fill Station ODH mitigation system. The Committee noted, and the NSLS agreed, that proper maintenance and testing of the hazard mitigation system (e.g., see 1.3.3.3 above) is important to the ODH classification in this area and must be maintained.

1.3.4. Mechanical Equipment Rooms (MER) 7 and 8
1.3.4.1. These rooms used to have operating cryogenic systems, which have been decommissioned. There are no cryogens in these areas.
1.3.4.2. There are, however, refrigerator systems for the Biology Cold Rooms.
1.3.4.3. The NSLS was requested to perform ODH analyses for these areas for postulated freon releases from the refrigerator systems.
1.4. Several Actions were developed during the course of this meeting. As discussed above, NSLS is requested to:
1.4.1. Compare the MER A ODH signage with the requirements of the Oxygen Deficiency Hazards (ODH), System Classification and Controls Subject Area and implement any required changes.
1.4.2. Review the Committee input offered at the meeting and revisit the MER A and the LN2 Filling Station ODH calculations. (See 1.3.2.7 and 1.3.3.6 above.) Please submit the ODH calculations to Committee Member Woody Glenn for LESHC review.
1.4.3. Perform ODH analyses of MER 7 and 8. (See 1.3.4.3.) Again, please submit these calculations for LESHC review.
1.4.4. Review the specifications for the MER A oxygen sensors to ensure they are designed for both helium and nitrogen environments. (See 1.3.2.7.3.)
1.4.5. At the completion of these actions, please contact the LESHC Chair to arrange for a Committee walk through.
1.5. The LESHC Secretary will track these actions to completion.

2. The Meeting was adjourned at 3:20 p.m.

Purpose

To Review NSLS ODH Calculation and Implemented Control Measures

Compiled by

Andrew Ackerman, Scott Buda, Mike Buckley, Payman Mortazavi

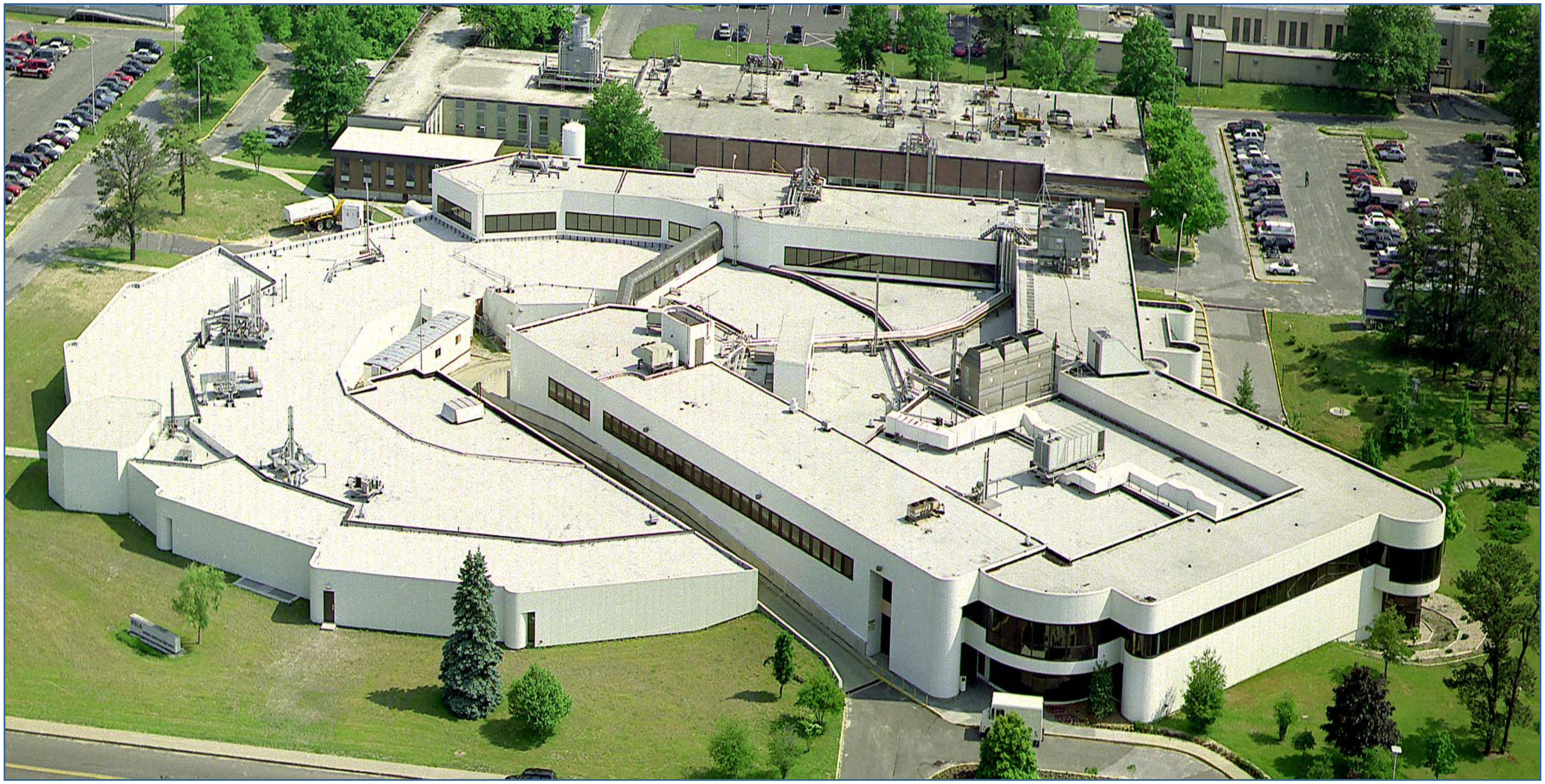
August 24, 2005

Agenda

- NSLS Facility Overview
  - ODH Area
  - X17 Cryo-Room Known as MER "A"
  - LN2 Filling Station (Buffer Area) referred to as West Roll-Up Door
- Systems Description
  - Flow Diagram
  - Brief Components Description
  - Supporting Documents (Photo & Operating Procedures)
- ODH Calculation Using SBMS Guidelines
  - Classifications
  - Failure Cases Considered
  - LHe Dewar Relief Augmentation
  - Calculation (See Attached Word Files)
  - Review Results (See Attached Word Files)
- Implemented Control Measures
  - Posted Signs
  - Installed Oxygen Monitors
  - Interlock System
  - Routine Preventive Maintenance Program & Functional Test

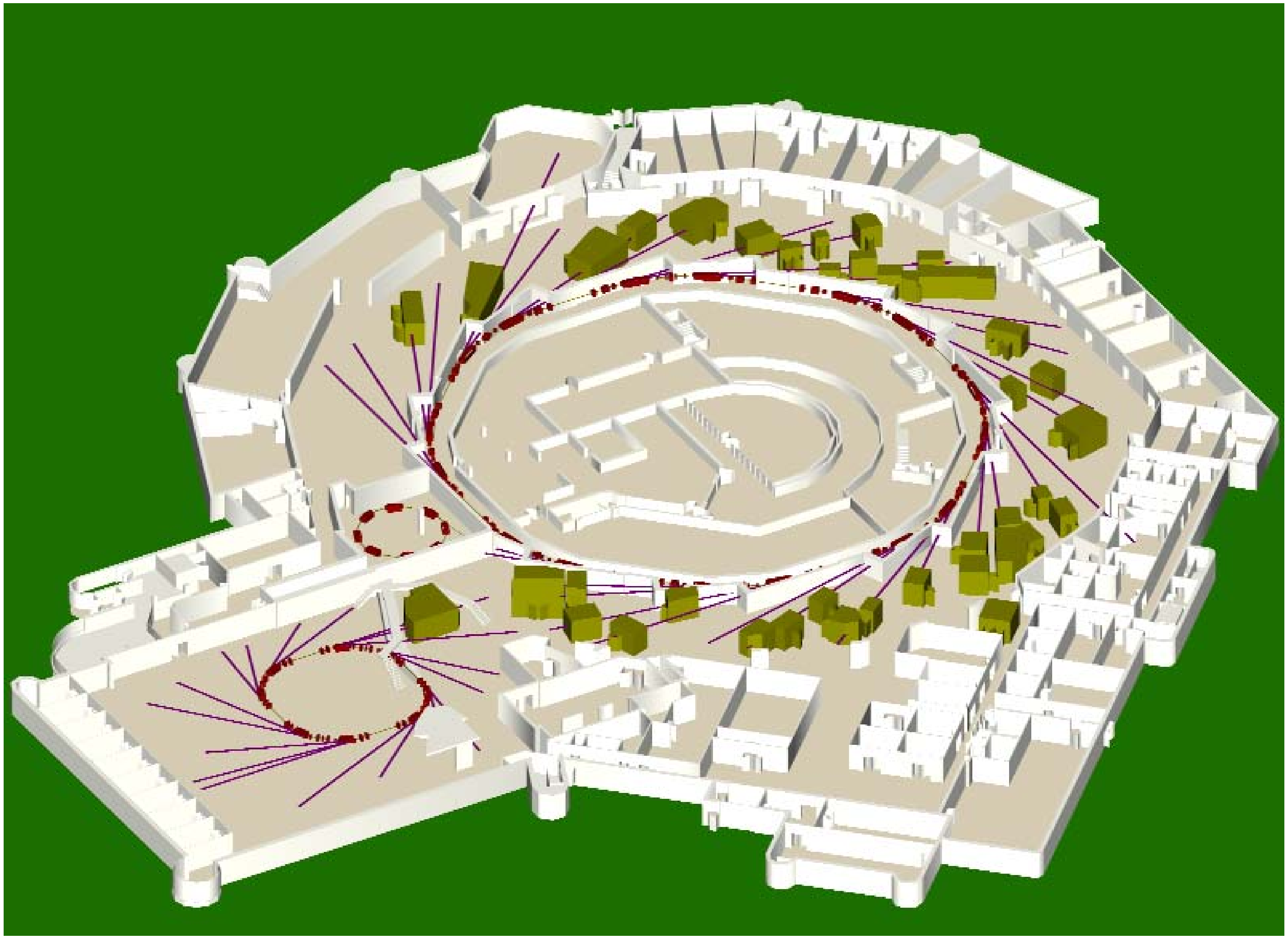
The National Synchrotron Light Source

Aerial View

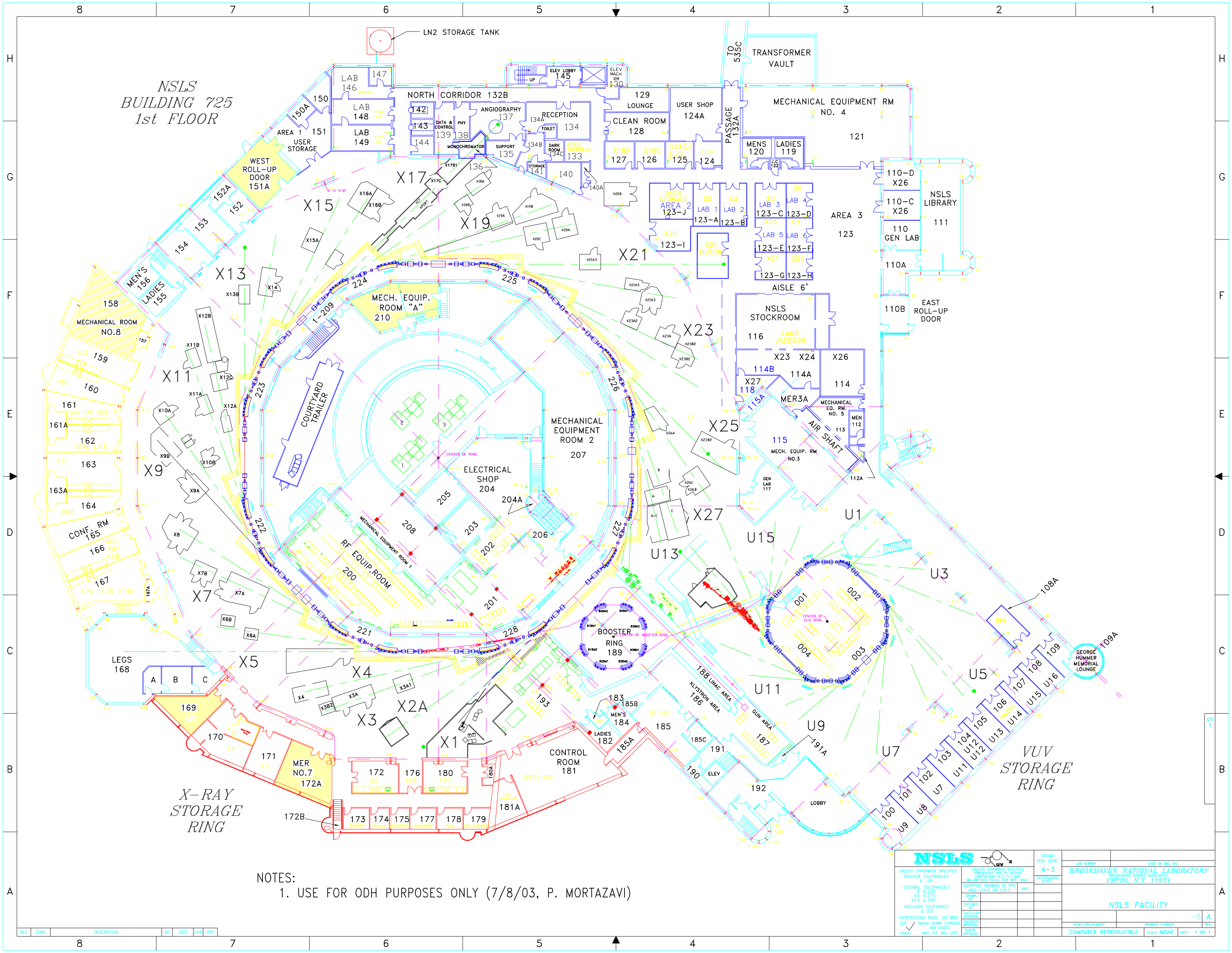


Brookhaven Science Associates
U.S. Department of Energy

NSLS, Building Cross Section



ODH Area

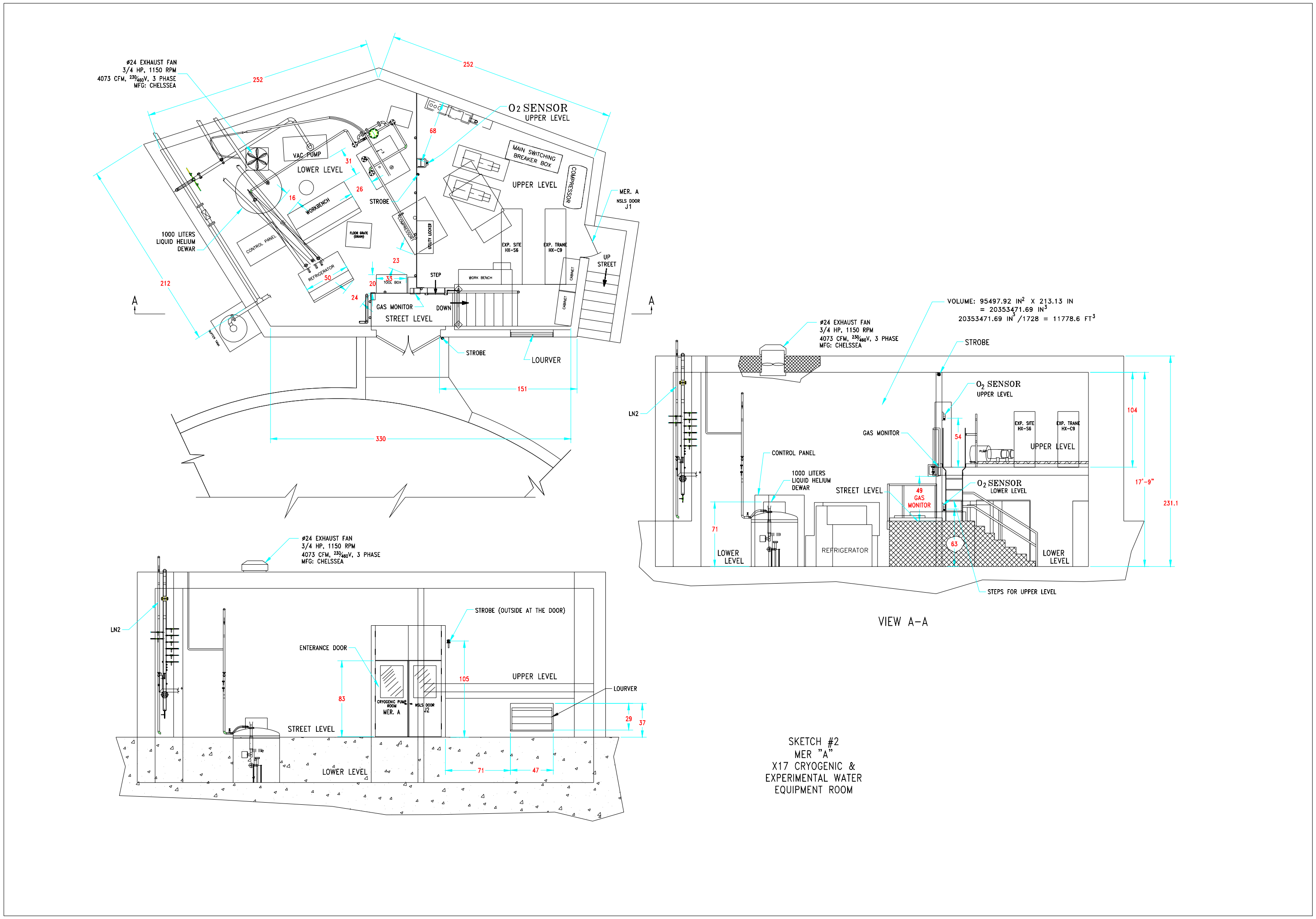


LN2 STORAGE TANK
NSLS BUILDING 725 1st FLOOR
TRANSFORMER VAULT
MECHANICAL EQUIPMENT RM NO. 4
NORTH CORRIDOR 132B
X-RAY STORAGE RING
VUV STORAGE RING
BOOSTER RING 189
MECHANICAL EQUIPMENT ROOM 2 207
ELECTRICAL SHOP 204
CONTROL ROOM 181
NSLS STOCKROOM
NSLS LIBRARY 111
EAST ROLL-UP DOOR
WEST ROLL-UP DOOR 151A
MECHANICAL ROOM NO.8
GEORGE HUMMER MEMORIAL LOUNGE
NOTES:
1. USE FOR ODH PURPOSES ONLY (7/8/03, P. MORTAZAVI)
NSLS
BROOKHAVEN NATIONAL LABORATORY
UPTON, N.Y. 11973
NSLS FACILITY

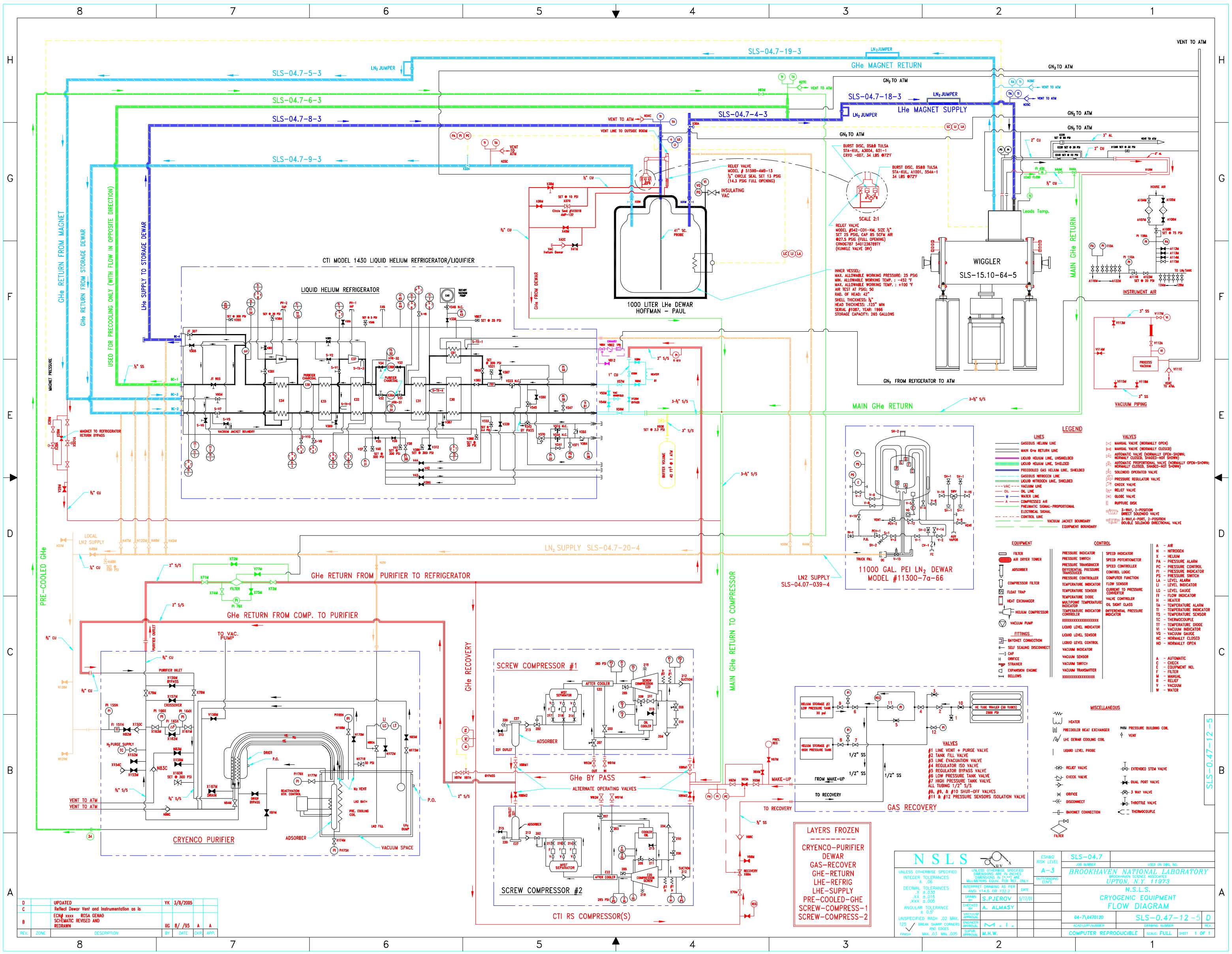
MER A


1-210
NOTICE
MER. A
J2
CAUTION
DO NOT ENTER
CAUTION
Oxygen Deficiency Hazard
When Beacon Illuminated or
Alarm Sounding
DO NOT ENTER
2005 8 2

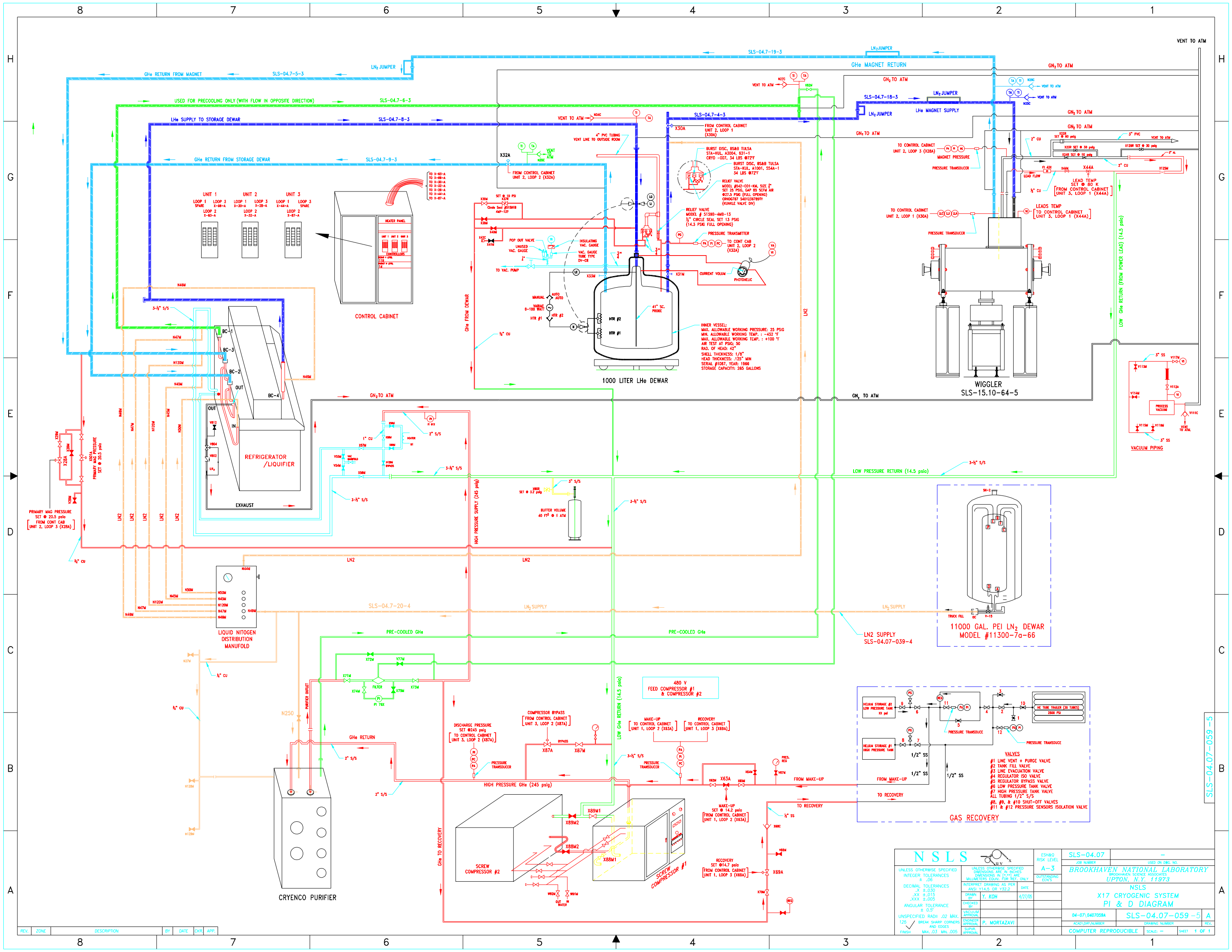
MER A, Foot Print



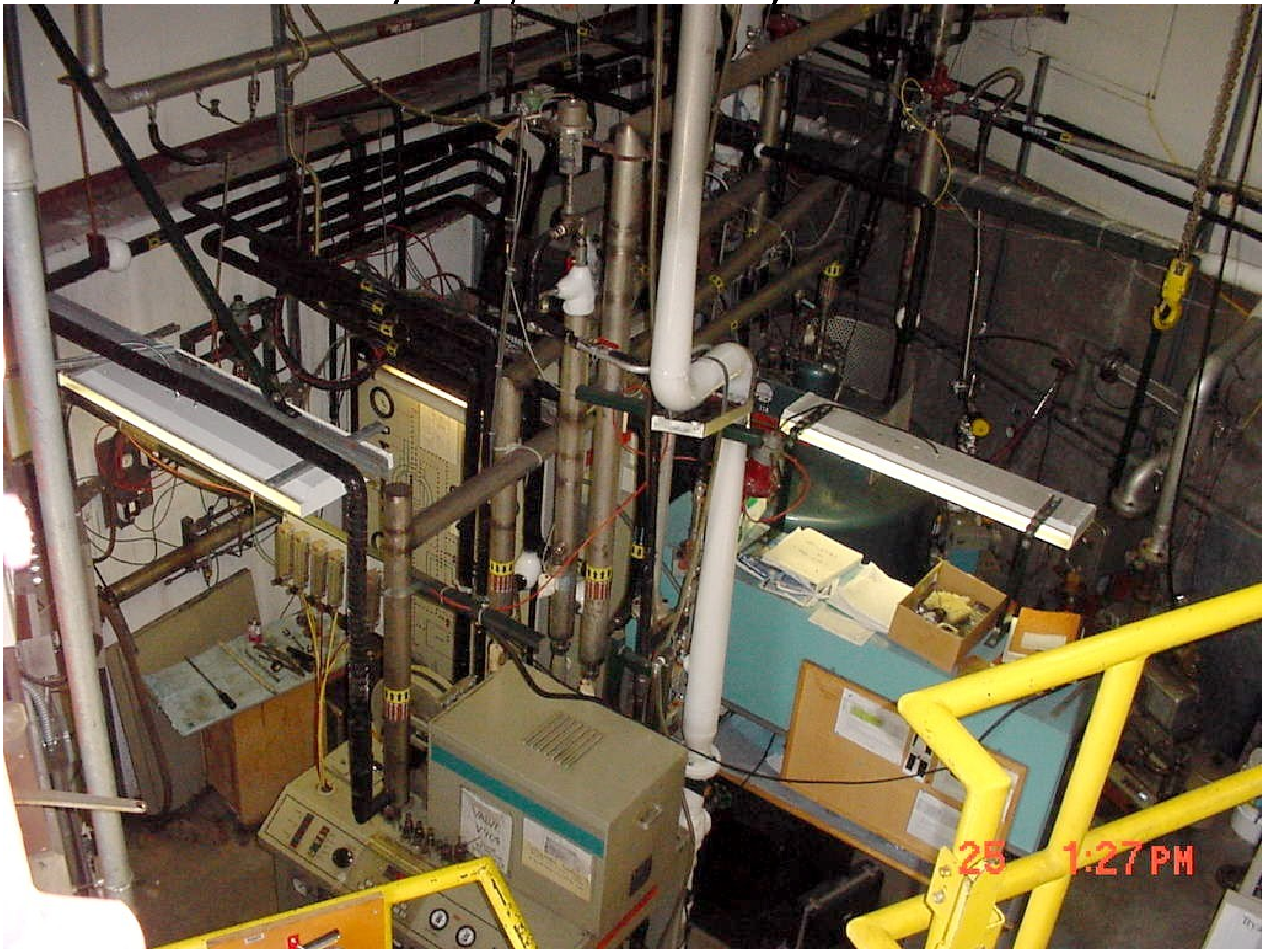
X17 Cryogenic, Flow Diagram



X17 Cryogenic, PI&D



X17 Cryogenic System



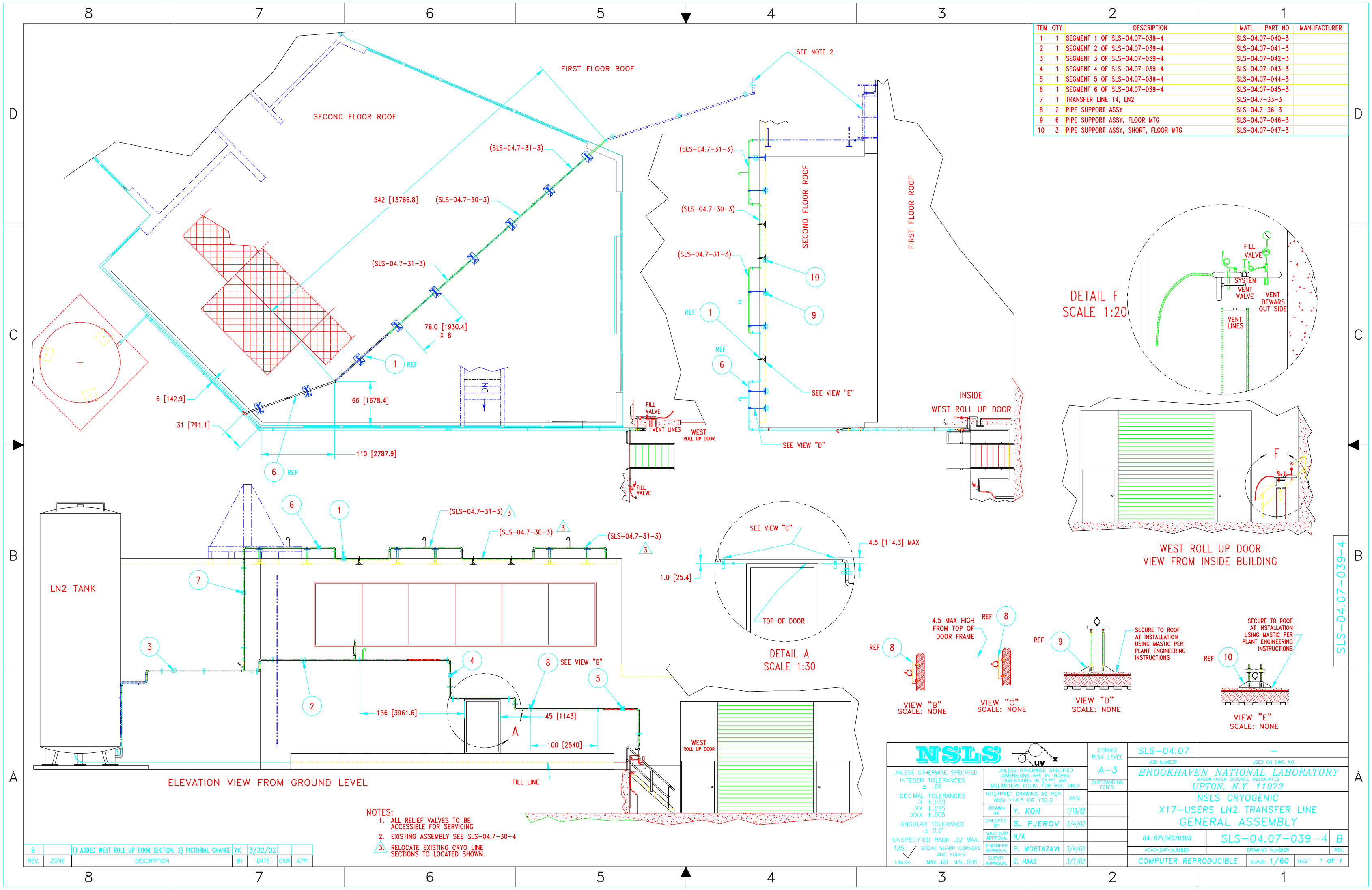
Main Components

O2 Monitoring System

LN2 Filling Station Area

LN2 Filling Station Components

LN2 Filling Station, Flow Diagram



ITEM	QTY	DESCRIPTION	MATL - PART NO	MANUFACTURER
1	1	SEGMENT 1 OF SLS-04.07-039-4	SLS-04.07-040-3	
2	1	SEGMENT 2 OF SLS-04.07-039-4	SLS-04.07-041-3	
3	1	SEGMENT 3 OF SLS-04.07-039-4	SLS-04.07-042-3	
4	1	SEGMENT 4 OF SLS-04.07-039-4	SLS-04.07-043-3	
5	1	SEGMENT 5 OF SLS-04.07-039-4	SLS-04.07-044-3	
6	1	SEGMENT 6 OF SLS-04.07-039-4	SLS-04.07-045-3	
7	1	TRANSFER LINE 14, LN2	SLS-04.7-33-3	
8	2	PIPE SUPPORT ASSY	SLS-04.7-36-3	
9	6	PIPE SUPPORT ASSY, FLOOR MTG	SLS-04.07-046-3	
10	3	PIPE SUPPORT ASSY, SHORT, FLOOR MTG	SLS-04.07-047-3	

LN2 Filling Station, System Description

- The buffer area between two west roll-up doors are primarily dedicated for the users to fill-up their Dewar with LN2 supplied via a vacuum jacketed transfer line from a nearby 40000 liters LN2 storage tank pressurized to 40-65 psig. The primary open/close solenoid valve is located near the fill station on the outside of the buffer area, which is operated by two-independent on/off push buttons located inside of the buffer area. There are posted filling instructions, relief valves and gauges that are clearly identified by large label directly posted against each of these components.

X17 Cryogenic, System Description

- X17 Cryogenic is a complete closed-cycle helium liquefaction and refrigeration system providing liquid helium to a superconducting wiggler magnet.
- The main components are consists of a CTI 1430 liqfr/refrg, two RS compressors, a 1000 lit helium dewar, an external Cryanco purifier, helium gas recovery system, various transfer lines, control system and a 4000 lit LN2 tank.
- It is a smi automated system, fully interlocked with well written operating instruction manuals.
- Hlelium Gas is initially liquefied from room temperature and stored in a 1000 liter Dewar serving as buffer storage tank, which supplies liquid helium on demand to the wiggler magnet.
- System is maintained at equilibrium via a semi automated boil-off within the buffer dewar.
- Routine preventive maintenance is performed to provide 24 – 7 operation.

Classification
(MER "A")

- Oxygen Concentration in Ventilated Spaces
- **Case B:** <u>Ventilation fans(s) drawing from the confined volume with the ventilation rate greater than the spill rate</u> (Q>R).
- The solution with the boundary condition of C=0.21 at t=0 is
-

$$C_r(t) = 0.21\left\{1 - \frac{R}{Q}\left[1 - e^{(-Qt/V)}\right]\right\}$$

Classification
(West Roll-Up Door)

- **Case C** <u>Ventilation fan(s) drawing from the confined volume with the ventilation rate less than or equal to the spill rate.</u>
- The solution with the boundary condition of C=0.21 at t=0 is

$$C_r(t) = 0.21e^{[-Rt/V]}$$

Considered Potential spill Sources

Considered unplanned source of discharge cryogen into the confined Space area of..

- MER "A“ are:

  1. From the LHe Dewar located inside of the room,
  2. From the liquid Nitrogen transfer line, partially inside of the room,

  3-4. From make-up/recovery lines.

  5. From interconnection GHe transfer pipe.
  6. From the liquid helium transfer lines due to rupture. However, analyses were also performed for other equipment failure cases as described later on.

- West Roll-up door is

  1. Continuous discharge of liquid nitrogen when both the solenoid and manual valves are stuck in open position

Failure Cases Considered

- **MER “A”**

1. Normal Operation, helium dewar relief valve opens, fan motor and fan flow switch or fan motor and alarm failure. $P_1 = P_{LHeD}\, P_{FanM}\, (P_{FanS} + P_{Alarm})$
2. Normal operation, LN2 lines develops major leak (including supply lines to the LHe shield lines, N=7), fan motor and fan flow switch or fan motor and alarm failure .
3. $P_2 = N \times P_{XLN2}\, P_{FanM}\, (P_{FanS} + P_{Alarm})$
3. Normal Operation, GHe make-up line ruptures (<3"), fan motor and fan flow switch or fan motor and alarm failure. $P_3 = P_{XGHe}\, P_{FanM}\, (P_{FanS} + P_{Alarm})$
4. Normal Operation, GHe Recovery line Ruptures (<3"), fan motor and fan flow switch or fan motor and alarm failure. $P_4 = P_{XGHe}\, P_{FanM}\, (P_{FanS} + P_{Alarm})$
5. Normal Operation, LHe transfer line ruptures (N=5), fan motor and fan flow switch or fan motor and alarm failure . $P_5 = N \times P_{XLHe}\, P_{FanM}\, (P_{FanS} + P_{Alarm})$
6. System in use, LHe Dewar relief opens (case A with highest fatality of 7.94×10^{-5}) and power failure. $P_6 = P_{LHeD}\, P_{power}$
7. Normal Operation, helium Dewar relief valves open (assume fatality factor one for maximum spill rate), fan motor and fan flow switch or fan motor and alarm failure
   $P_7 = P_{LHeD}\, P_{FanM}\, (P_{FanS} + P_{Alarm})$

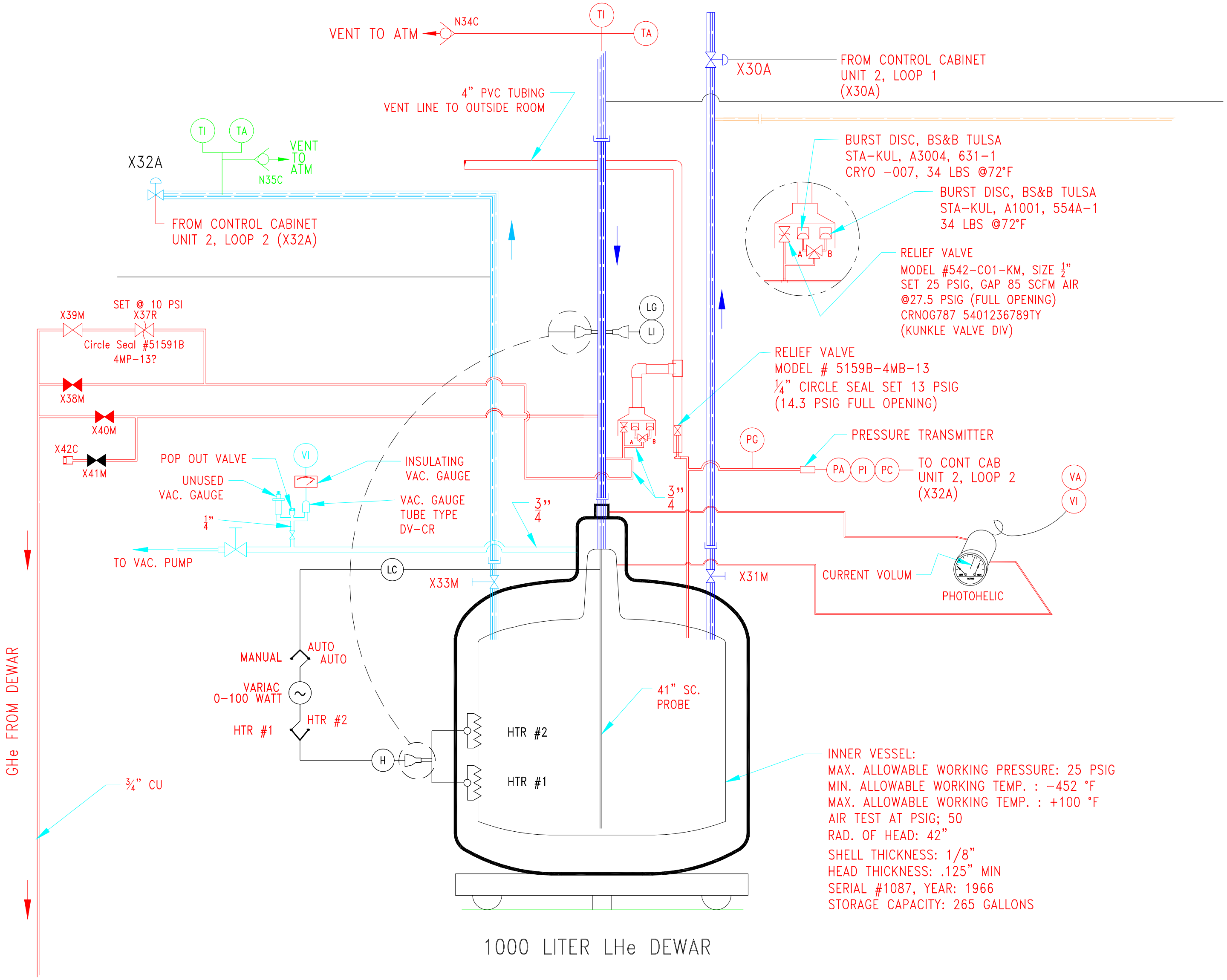
- **West Roll-up Door**

1. System in use, LN2 transfers line leak/rupture and alarm failure. $P1 = (P_{LN2})(PA)$
2. System in use, LN2 transfers line leak/rupture and power failure. $P2 =(P_{LN2})(P_P)$
3. System in use, LN2 transfers line leak/rupture and door fails to open due to electric motor fails to run. $P3 = (P_{LN2})(P_M)$
4. System in use, Solenoid valve failed to operate (close). $P4 = (P_{LN2})(P_s)$

LHe Dewar Relief Augmentation

- Performed Relief Size Calculation
- Added New ½" Relief Valve
- Added two ½" Redundant Burst Disk
- Routed Exhaust Gas to Outside Building

1000 Lit LHe Dewar



1000 LITER LHe DEWAR

ODH Clasification

- **ODH Class** **Fatalities /Hr**
- No Classification Required 0 (Oxygen concentration not less than 18%)

  0 $<10^{-7}$[note 1]
- 1 $>=10^{-7}$ but $<10^{-5}$
- 2 $>=10^{-5}$ but $<10^{-3}$
- 3 $>=10^{-3}$ but $<10^{-1}$
- 4 $>=10^{-1}$

- **Both MER “A” and West Roll-up door were found an ODH Class “0”**

ODH CONTROL MEASURES

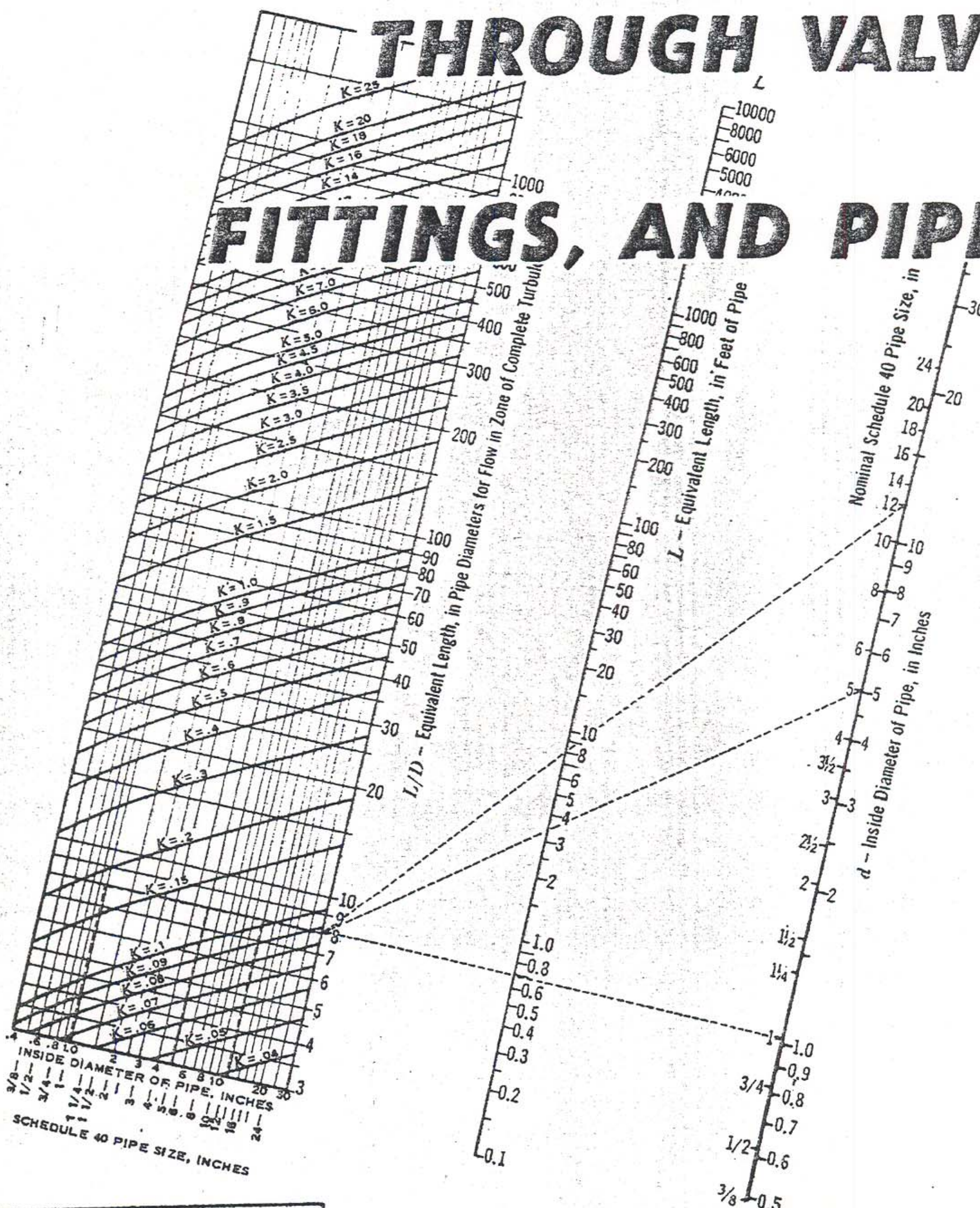
	» **ODH Hazard Class**				
Environmental Controls	**0**	**1**	**2**	**3**	**4**
1. Warning signs	X	X	X	X	X
2. Ventilation			X	X	X
ODH-Qualified Personnel Controls					
3. Medical approval as ODH-qualified		X	X	X	X
4. ODH training	X	X	X	X	X
5. Personal oxygen monitor		X	X	X	X
6. Self-rescue supplied atmosphere respirator		X	X	X	X
7. Multiple personnel in communication		X	X	X	
8. Unexposed observer				X	X
9. Self-contained breathing apparatus					X

Implemented Control Measures

- MER “A” & West Roll-Up Door
  - Posted Sign
  - ODH Training
  - Interlocked Oxygen Monitoring System
  - Implemented Routine Preventive Maintenance Program & Interlock Functional Test.

FLOW OF FLUIDS

THROUGH VALVES, FITTINGS, AND PIPE



CRANE®

Technical Paper No. 410

Summary of Formulas — continued

Limitations of Darcy formula

Non-compressible flow; liquids:

The Darcy formula may be used without restriction for the flow of water, oil, and other liquids in pipe. However, when extreme velocities occurring in pipe cause the downstream pressure to fall to the vapor pressure of the liquid, cavitation occurs and calculated flow rates are inaccurate.

Compressible flow; gases and vapors:

When pressure drop is less than 10% of P_1, use ρ or $\overline{V}$ based on either inlet or outlet conditions.

When pressure drop is greater than 10% of P_1 but less than 40% of P_1, use the average of ρ or $\overline{V}$ based on inlet and outlet conditions, or use Equation 3-20.

When pressure drop is greater than 40% of P_1, use the rational or empirical formulas given on this page for compressible flow, or use Equation 3-20 (for theory, see page 1-9).

Isothermal flow of gas in pipe lines

Equation 3-7

$$w = \sqrt{\frac{144 g A^2}{\overline{V}_1\left(f\frac{L}{D} + 2\log_e \frac{P'_1}{P'_2}\right)}\left(\frac{(P'_1)^2 - (P'_2)^2}{P'_1}\right)}$$

$$w = 0.371\sqrt{\frac{d^4}{\overline{V}_1\left(f\frac{L}{D} + 2\log_e \frac{P'_1}{P'_2}\right)}\left(\frac{(P'_1)^2 - (P'_2)^2}{P'_1}\right)}$$

Simplified compressible flow for long pipe lines

Equation 3-7a

$$w = \sqrt{\left(\frac{144\, g A^2}{\overline{V}_1 f \frac{L}{D}}\right)\left(\frac{(P'_1)^2 - (P'_2)^2}{P'_1}\right)}$$

$$w = 0.1072\sqrt{\left(\frac{d^5}{\overline{V}_1 f L}\right)\left(\frac{(P'_1)^2 - (P'_2)^2}{P'_1}\right)}$$

$$q'_h = 114.2\sqrt{\left(\frac{(P'_1)^2 - (P'_2)^2}{f\, L_m\, T\, S_g}\right) d^5}$$

Maximum (sonic) velocity of compressible fluids in pipe

The maximum possible velocity of a compressible fluid in a pipe is equivalent to the speed of sound in the fluid; this is expressed as:

Equation 3-8

$$v_s = \sqrt{k\, g\, R\, T}$$

$$v_s = \sqrt{k\, g\, 144 P' \overline{V}}$$

$$v_s = 68.1\sqrt{k\, P' \overline{V}}$$

Empirical formulas for the flow of water, steam, and gas

Although the rational method (using Darcy's formula) for solving flow problems has been recommended in this paper, some engineers prefer to use empirical formulas.

Hazen and Williams formula for flow of water: *Equation 3-9*

$$Q = 0.442\, d^{2.63}\, c\left(\frac{P_1 - P_2}{L}\right)^{0.54}$$

where:
c = 140 for new steel pipe
c = 130 for new cast iron pipe
c = 110 for riveted pipe

Equation 3-10
(deleted)

Spitzglass formula for low pressure gas: (pressure less than one pound gauge) *Equation 3-11*

$$q'_h = 3550\sqrt{\frac{\Delta h_w\, d^5}{S_g L\left(1 + \frac{3.6}{d} + 0.03\, d\right)}}$$

Flowing temperature is 60 F.

Weymouth formula for high pressure gas: *Equation 3-12*

$$q'_h = 28.0\, d^{2.667}\sqrt{\left(\frac{(P'_1)^2 - (P'_2)^2}{S_g\, L_m}\right)\left(\frac{520}{T}\right)}$$

Panhandle formula[3] for natural gas pipe lines 6 to 24-inch diameter and R_e = (5 x 10^6) to (14 x 10^6): *Equation 3-13*

$$q'_h = 36.8E\, d^{2.6182}\left(\frac{(P'_1)^2 - (P'_2)^2}{L_m}\right)^{0.5394}$$

where: gas temperature = 60 F
S_g = 0.6
E = flow efficiency
E = 1.00 (100%) for brand new pipe without any bends, elbows, valves, and change of pipe diameter or elevation
E = 0.95 for very good operating conditions
E = 0.92 for average operating conditions
E = 0.85 for unusually unfavorable operating conditions

Summary of Formulas — continued

Head loss and pressure drop through valves and fittings

Head loss through valves and fittings is generally given in terms of resistance coefficient K which indicates static head loss through a valve in terms of "velocity head", or, equivalent length in pipe diameters L/D that will cause the same head loss as the valve.

From Darcy's formula, head loss through a pipe is:

$$h_L = f\frac{L}{D}\frac{v^2}{2g} \qquad \textbf{Equation 3-5}$$

and head loss through a valve is:

$$h_L = K\frac{v^2}{2g} \qquad \textbf{Equation 3-14}$$

therefore: $K = f\frac{L}{D}$ **Equation 3-15**

To eliminate needless duplication of formulas, the following are all given in terms of K. Whenever necessary, substitute $(f\,L/D)$ for (K).

$$h_L = \frac{522\,Kq^2}{d^4} = 0.002\,59\frac{KQ^2}{d^4} \qquad \textbf{Equation 3-14}$$

$$h_L = 0.001\,270\frac{KB^2}{d^4} = 0.000\,0403\frac{KW^2\bar{V}^2}{d^4}$$

$$\Delta P = 0.000\,1078\,K\rho v^2 = 0.000\,000\,0300\,K\rho V^2$$

$$\Delta P = 3.62\frac{K\rho q^2}{d^4} = 0.000\,017\,99\frac{K\rho Q^2}{d^4}$$

$$\Delta P = 0.000\,008\,82\frac{K\rho B^2}{d^4}$$

$$\Delta P = 0.000\,000\,280\frac{KW^2\bar{V}}{d^4}$$

$$\Delta P = 0.000\,000\,000\,605\frac{K(q'_h)^2\,T\,S_g}{d^4\,P'}$$

$$\Delta P = 0.000\,000\,001\,633\frac{K\,(q'_h)^2\,S_g^2}{d^4\,\rho}$$

For compressible flow with h_L or ΔP greater than approximately 10% of inlet absolute pressure, the denominator should be multiplied by Y^2. For values of Y, see page A-22.

Pressure drop and flow of liquids of low viscosity using flow coefficient

$$\Delta P = \left(\frac{Q}{C_V}\right)^2\frac{\rho}{62.4} \qquad \textbf{Equation 3-16}$$

$$Q = C_V\sqrt{\Delta P\frac{62.4}{\rho}} = 7.90\,C_V\sqrt{\frac{\Delta P}{\rho}}$$

$$C_V = Q\sqrt{\frac{\rho}{\Delta P\,(62.4)}} = \frac{29.9\,d^2}{\sqrt{f\,L/D}} = \frac{29.9\,d^2}{\sqrt{K}}$$

$$K = \frac{891\,d^4}{(C_V)^2}$$

Resistance coefficient, K, for sudden and gradual enlargements in pipes

If, $\theta \leqq 45°$,

$$K_1 = 2.6\sin\frac{\theta}{2}\,(1-\beta^2)^2 \qquad \text{*Equation 3-17}$$

If, $45° < \theta \leqq 180°$,

$$K_1 = (1-\beta^2)^2 \qquad \text{*Equation 3-17.1}$$

Resistance coefficient, K, for sudden and gradual contractions in pipes

If, $\theta \leqq 45°$,

$$K_1 = 0.8\sin\frac{\theta}{2}\,(1-\beta^2) \qquad \text{*Equation 3-18}$$

If, $45° < \theta \leqq 180°$,

$$K_1 = 0.5\sqrt{\sin\frac{\theta}{2}}\,(1-\beta^2) \qquad \text{*Equation 3-18.1}$$

**Note:* The values of the resistance coefficients (K) in equations 3-17, 3-17.1, 3-18, and 3-18.1 are based on the velocity in the small pipe. To determine K values in terms of the greater diameter, divide the equations by β^4.

Discharge of fluid through valves, fittings, and pipe; Darcy's formula

Liquid flow: **Equation 3-19**

$$q = 0.0438\,d^2\sqrt{\frac{h_L}{K}} = 0.525\,d^2\sqrt{\frac{\Delta P}{K\rho}}$$

$$Q = 19.65\,d^2\sqrt{\frac{h_L}{K}} = 236\,d^2\sqrt{\frac{\Delta P}{K\rho}}$$

$$w = 0.0438\,\rho d^2\sqrt{\frac{h_L}{K}} = 0.525\,d^2\sqrt{\frac{\Delta P\rho}{K}}$$

$$W = 157.6\,\rho d^2\sqrt{\frac{h_L}{K}} = 1891\,d^2\sqrt{\frac{\Delta P\rho}{K}}$$

Compressible flow:

$$q'_h = 40\,700\,Yd^2\sqrt{\frac{\Delta P\,P'_1}{KT_1\,S_g}} \qquad \textbf{Equation 3-20}$$

$$q'_h = 24\,700\frac{Yd^2}{S_g}\sqrt{\frac{\Delta P\,\rho_1}{K}}$$

$$q'_m = 678\,Yd^2\sqrt{\frac{\Delta P\,P'_1}{KT_1\,S_g}} = 412\frac{Yd^2}{S_g}\sqrt{\frac{\Delta P\,\rho_1}{K}}$$

$$q' = 11.30\,Yd^2\sqrt{\frac{\Delta PP'_1}{KT_1\,S_g}} = 6.87\frac{Yd^2}{S_g}\sqrt{\frac{\Delta P\rho_1}{K}}$$

$$w = 0.525\,Yd^2\sqrt{\frac{\Delta P}{K\bar{V}_1}} \qquad W = 1891\,Yd^2\sqrt{\frac{\Delta P}{K\bar{V}_1}}$$

Values of Y are shown on page A-22. For K, Y, and ΔP determination, see examples on pages 4-13 and 4-14.

Viscosity of Gases and Vapors

The curves for hydrocarbon vapors and natural gases in the chart at the upper right are taken from Maxwell[15]; the curves for all other gases (except helium [7]) in the chart are based upon Sutherland's formula, as follows:

$$\mu = \mu_0 \left(\frac{0.555\ T_0 + C}{0.555\ T + C}\right)\left(\frac{T}{T_0}\right)^{3/2}$$

where:

μ = viscosity, in centipoise at temperature T.

μ_0 = viscosity, in centipoise at temperature T_0.

T = absolute temperature, in degrees Rankine (460 + deg. F) for which viscosity is desired.

T_0 = absolute temperature, in degrees Rankine, for which viscosity is known.

C = Sutherland's constant.

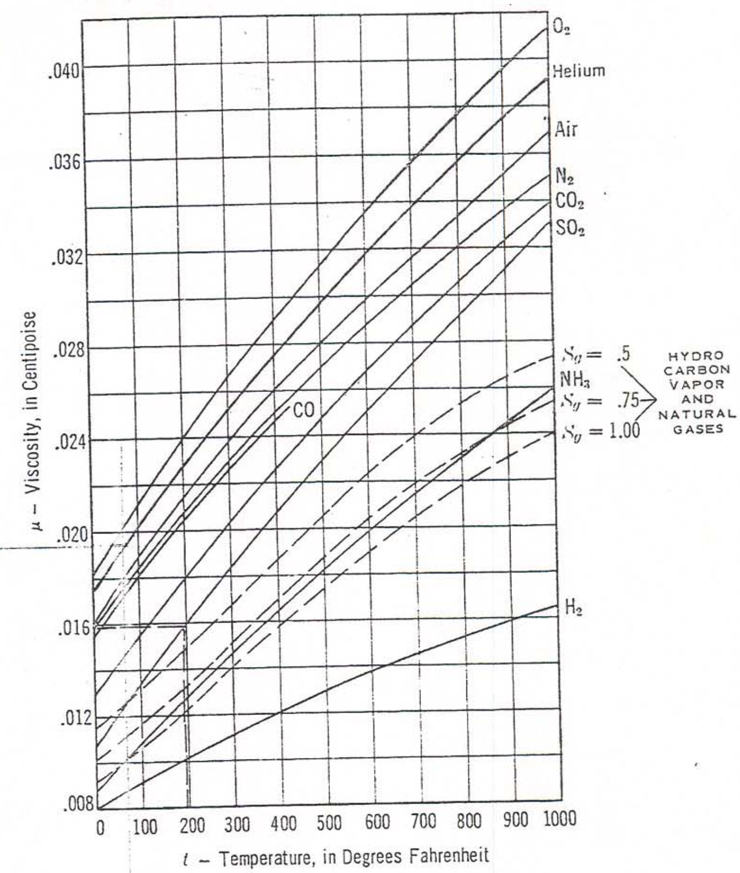
Note: The variation of viscosity with pressure is small for most gases. For gases given on this page, the correction of viscosity for pressure is less than 10 per cent for pressures up to 500 pounds per square inch.

Fluid	Approximate Values of "C"
O_2	127
Air	120
N_2	111
CO_2	240
CO	118
SO_2	416
NH_3	370
H_2	72

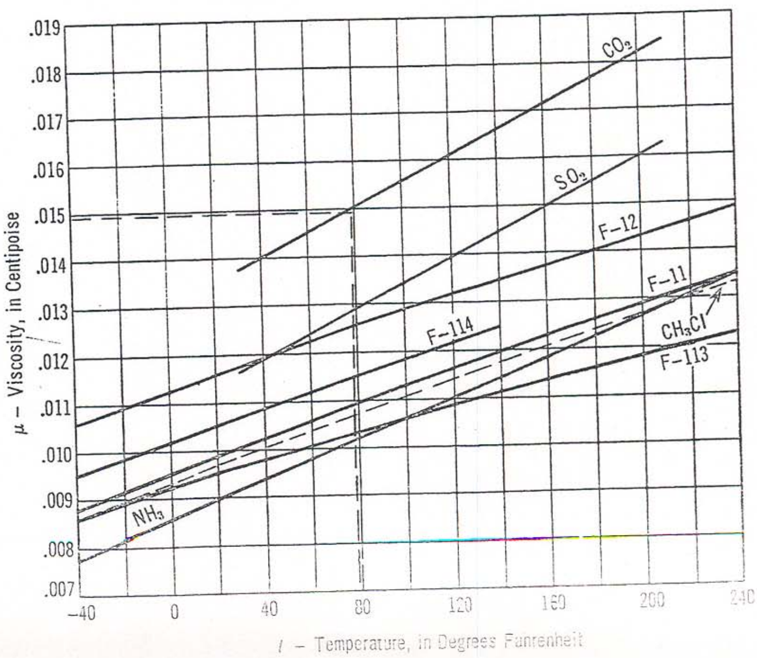
Upper chart example: The viscosity of sulphur dioxide gas (SO_2) at 200 F is 0.016 centipoise.

Lower chart example: The viscosity of carbon dioxide gas (CO_2) at about 80 F is 0.015 centipoise.

Viscosity of Various Gases



Viscosity of Refrigerant Vapors[11]
(saturated and superheated vapors)



Physical Properties of Gases[13]

(Approximate values at 68 F and 14.7 psia)

c_p = specific heat at constant pressure
c_v = specific heat at constant volume

Name of Gas	Chemical Formula or Symbol	Approx. Molecular Weight M	Weight Density, Pounds per Cubic Foot ρ	Specific Gravity Relative to Air S_g	Individual Gas Constant R	Specific Heat at Room Temperature Btu/Lb °F c_p	Specific Heat at Room Temperature Btu/Lb °F c_v	Heat Capacity per Cubic Foot c_p	Heat Capacity per Cubic Foot c_v	k equal to c_p/c_v
Acetylene (ethyne)	C_2H_2	26.0	.0682	0.907	59.4	0.350	0.269	.0239	.0184	1.30
Air	—	29.0	.0752	1.000	53.3	0.241	0.172	.0181	.0129	1.40
Ammonia	NH_3	17.0	.0448	0.596	91.0	0.523	0.396	.0234	.0178	1.32
Argon	A	39.9	.1037	1.379	38.7	0.124	0.074	.0129	.0077	1.67
Butane	C_4H_{10}	58.1	.1554	2.067	26.5	0.395	0.356	.0614	.0553	1.11
Carbon dioxide	CO_2	44.0	.1150	1.529	35.1	0.205	0.158	.0236	.0181	1.30
Carbon monoxide	CO	28.0	.0727	0.967	55.2	0.243	0.173	.0177	.0126	1.40
Chlorine	Cl_2	70.9	.1869	2.486	21.8	0.115	0.086	.0215	.0162	1.33
Ethane	C_2H_6	30.0	.0789	1.049	51.5	0.386	0.316	.0305	.0250	1.22
Ethylene	C_2H_4	28.0	.0733	0.975	55.1	0.400	0.329	.0293	.0240	1.22
Helium	He	4.0	.01039	0.1381	386.3	1.250	0.754	.0130	.0078	1.66
Hydrogen chloride	HCl	36.5	.0954	1.268	42.4	0.191	0.135	.0182	.0129	1.41
Hydrogen	H_2	2.0	.00523	0.0695	766.8	3.420	2.426	.0179	.0127	1.41
Hydrogen sulphide	H_2S	34.1	.0895	1.190	45.2	0.243	0.187	.0217	.0167	1.30
Methane	CH_4	16.0	.0417	0.554	96.4	0.593	0.449	.0247	.0187	1.32
Methyl chloride	CH_3Cl	50.5	.1342	1.785	30.6	0.240	0.200	.0322	.0268	1.20
Natural gas	—	19.5	.0502	0.667	79.1	0.560	0.441	.0281	.0221	1.27
Nitric oxide	NO	30.0	.0780	1.037	51.5	0.231	0.165	.0180	.0129	1.40
Nitrogen	N_2	28.0	.0727	0.967	55.2	0.247	0.176	.0180	.0127	1.41
Nitrous oxide	N_2O	44.0	.1151	1.530	35.1	0.221	0.169	.0254	.0194	1.31
Oxygen	O_2	32.0	.0831	1.105	48.3	0.217	0.155	.0180	.0129	1.40
Propane	C_3H_8	44.1	.1175	1.562	35.0	0.393	0.342	.0462	.0402	1.15
Propene (propylene)	C_3H_6	42.1	.1091	1.451	36.8	0.358	0.314	.0391	.0343	1.14
Sulphur dioxide	SO_2	64.1	.1703	2.264	24.0	0.154	0.122	.0262	.0208	1.26

Molecular Weight, Specific Gravity, Individual Gas Constant, and Specific Heat values were abstracted from, or based on, data in Table 24 of Mark's "Standard Handbook for Mechanical Engineers" (seventh edition).

Weight Density values were obtained by multiplying density of air by specific gravity of gas. For values at 60 F, multiply by 1.0154.

Natural Gas values are representative only. Exact characteristics require knowledge of specific constituents.

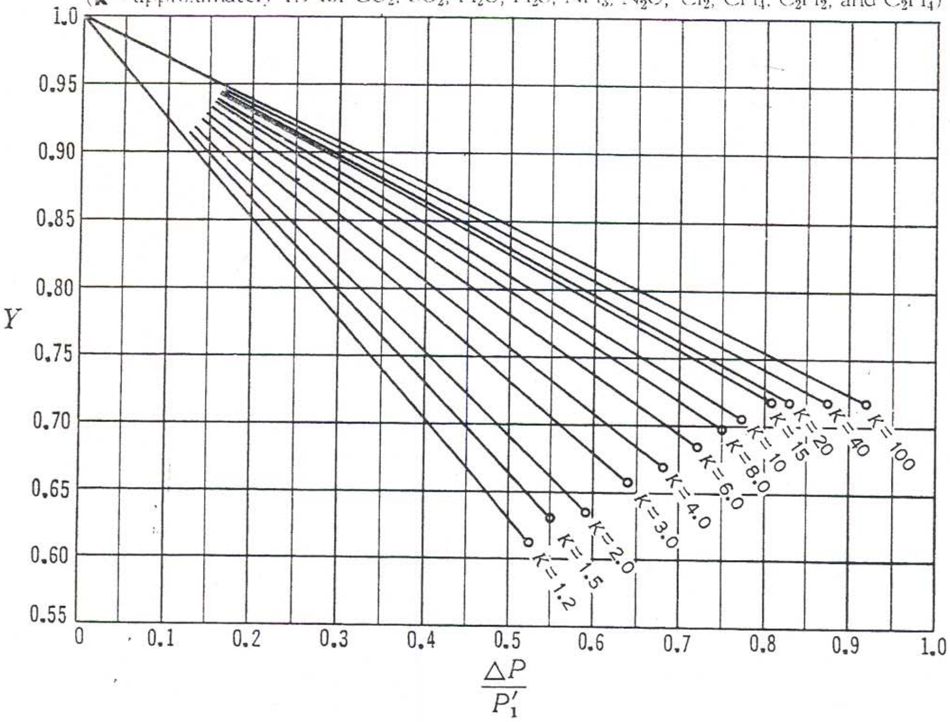
Volumetric Composition and Specific Gravity of Gaseous Fuels[13]

Type of Gas	Chemical Composition Percent by Volume: Hydrogen	Carbon Monoxide	Paraffin Hydrocarbons: Methane	Paraffin Hydrocarbons: Ethane	Illuminants: Ethylene	Illuminants: Benzene	Oxygen	Nitrogen	Carbon Dioxide	Specific Gravity Relative to Air S_g
Natural Gas, Pittsburgh	...	...	83.4	15.8	...	...	...	0.8	...	0.61
Producer Gas from Bituminous Coal	14.0	27.0	3.0	...	...	...	0.6	50.9	4.5	0.86
Blast Furnace Gas	1.0	27.5	...	...	...	...	...	60.0	11.5	1.02
Blue Water Gas from Coke	47.3	37.0	1.3	...	...	...	0.7	8.3	5.4	0.57
Carbureted Water Gas	40.5	34.0	10.2	...	6.1	2.8	0.5	2.9	3.0	0.63
Coal Gas (Cont. Vertical Retorts)	54.5	10.9	24.2	...	1.5	1.3	0.2	4.4	3.0	0.42
Coke-Oven Gas	46.5	6.3	32.1	...	3.5	0.5	0.8	8.1	2.2	0.44
Refinery Oil Gas (Vapor Phase)	13.1	1.2	23.3	21.7	39.6	...	1.0	...	0.1	0.89
Oil Gas, Pacific Coast	48.6	12.7	26.3	...	2.7	1.1	0.3	3.6	4.7	0.47

Net Expansion Factor Y for Compressible Flow Through Pipe to a Larger Flow Area

k = 1.3

(k = approximately 1.3 for CO_2, SO_2, H_2O, H_2S, NH_3, N_2O, Cl_2, CH_4, C_2H_2, and C_2H_4)

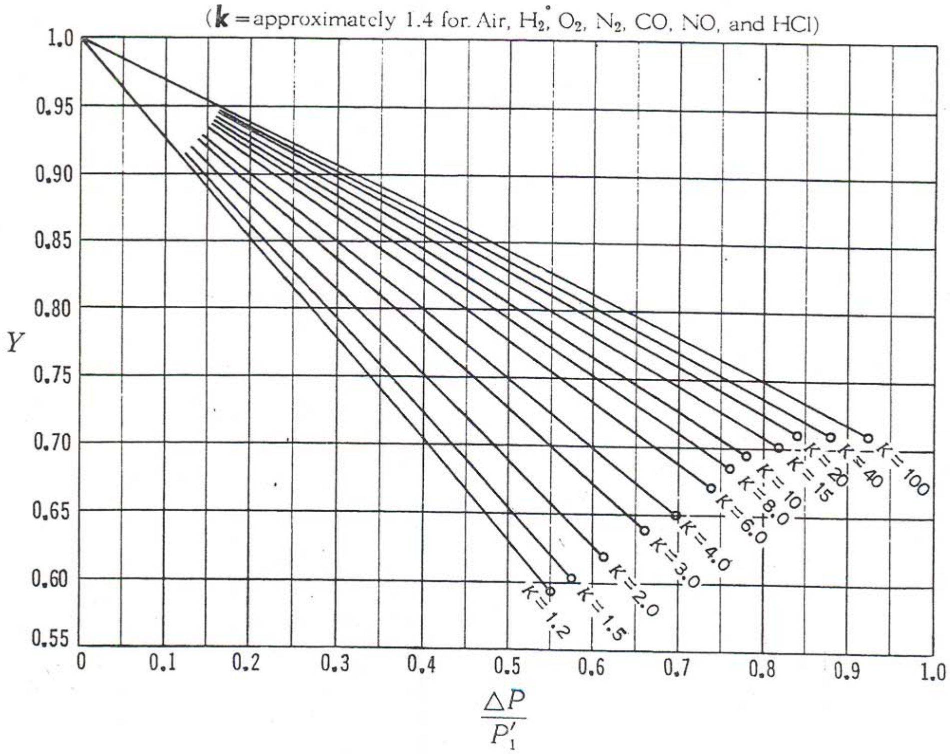


Limiting Factors For Sonic Velocity
$k = 1.3$

K	$\frac{\Delta P}{P'_1}$	Y
1.2	.525	.612
1.5	.550	.631
2.0	.593	.635
3	.642	.658
4	.678	.670
6	.722	.685
8	.750	.698
10	.773	.705
15	.807	.718
20	.831	.718
40	.877	.718
100	.920	.718

k = 1.4

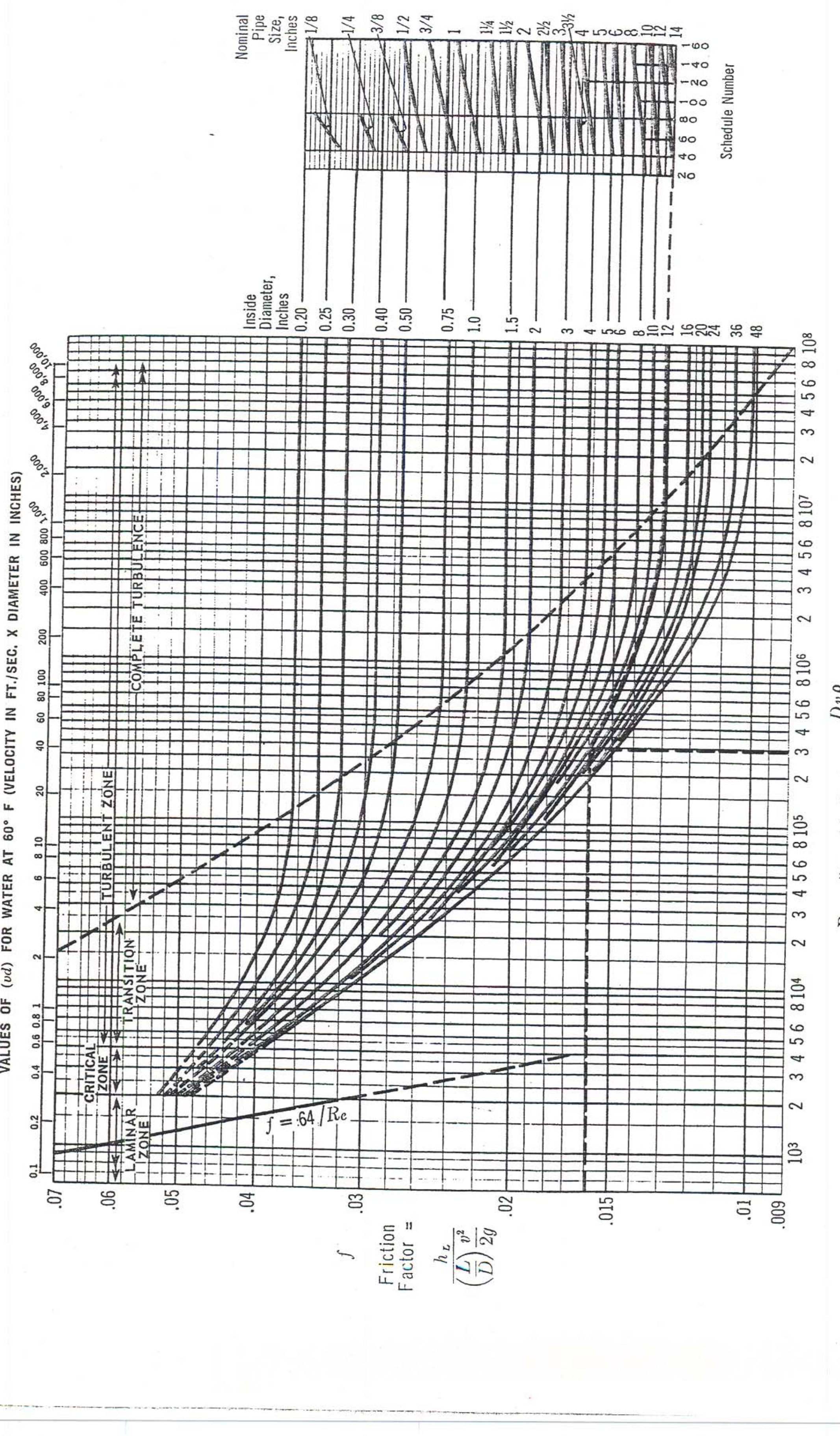
(k = approximately 1.4 for Air, H_2, O_2, N_2, CO, NO, and HCl)



Limiting Factors For Sonic Velocity
$k = 1.4$

K	$\frac{\Delta P}{P'_1}$	Y
1.2	.552	.588
1.5	.576	.606
2.0	.612	.622
3	.662	.639
4	.697	.649
6	.737	.671
8	.762	.685
10	.784	.695
15	.818	.702
20	.839	.710
40	.883	.710
100	.926	.710

Friction Factors for Clean Commercial Steel Pipe[13]



For other forms of the R_e equation, see page 3-2.

Problem: Determine the friction factor for 12-inch Schedule 40 pipe at a flow having a Reynolds number of 300,000.

Solution: The friction factor (f) equals 0.016.

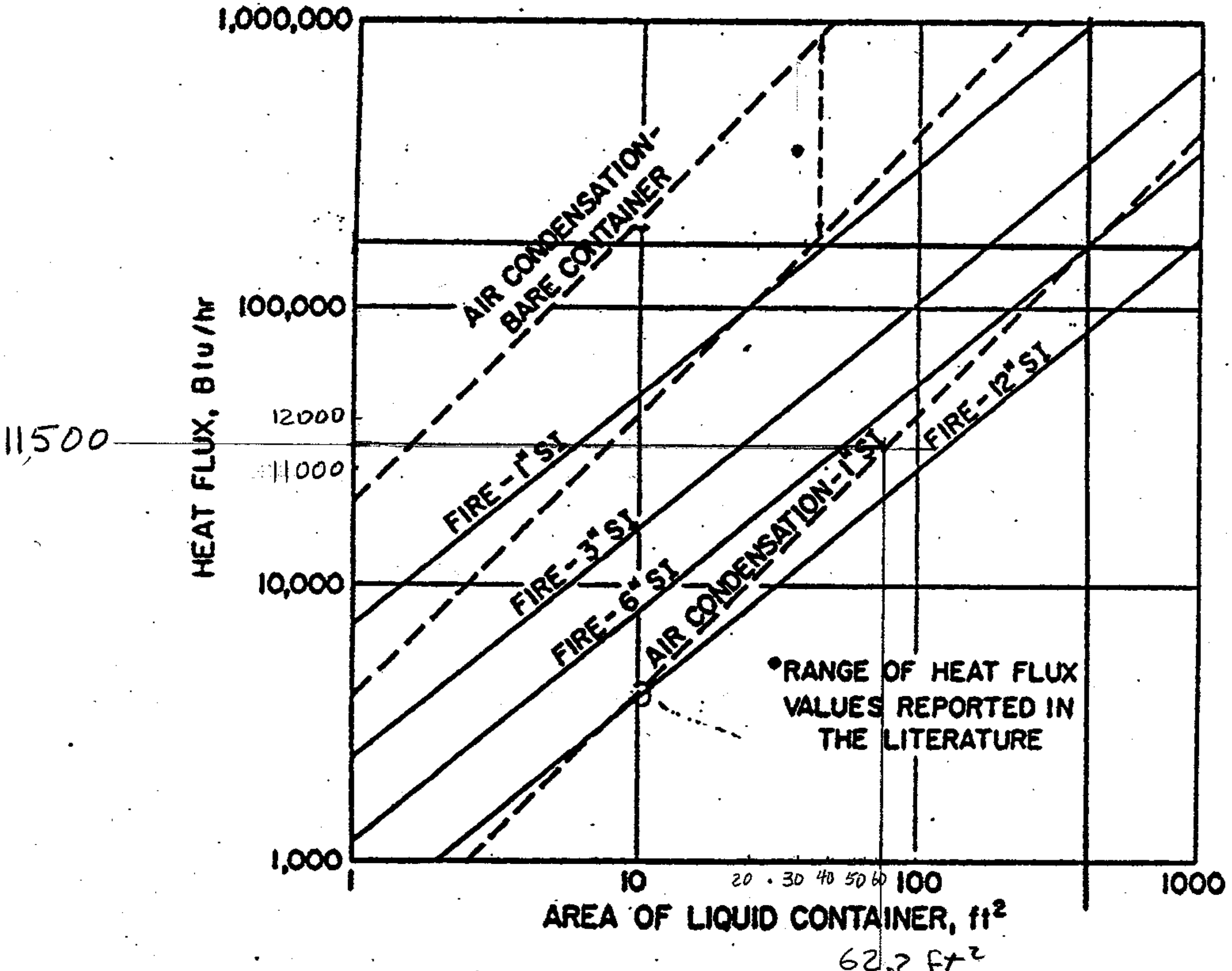


Figure 6.3. *Estimated total heat flux versus area for air condensation and fire conditions in multilayer (SI) insulated liquid helium containers.*

Oxygen Concentration in Ventilated Spaces

The oxygen concentration in a confined volume during and after a release of an inert gas may be approximated for three different cases:

A. Ventilation fan(s) blowing into the confined volume.
B. Ventilation fan(s) drawing from the confined volume with the ventilation rate greater than the spill rate.
C. Ventilation fan(s) drawing from the confined volume with the ventilation rate less than or equal to the spill rate.

For each case, the differential equation and its solution is given, based on an oxygen mass balance for the confined volume. The following definitions and assumptions are common for each case.

Definitions

C = oxygen concentration
C_r = oxygen concentration during the release
C_e = oxygen concentration after the release has ended
Q = ventilation rate of fan(s), (cfm or m^3/s)
R = spill rate into confined volume, (scfm or m^3/s)
t = time (minutes or seconds), beginning of release is at t=0
t_e = time when release has ended, (minutes or seconds)
V = confined volume, (ft^3 or m^3)

Assumptions

- Complete and instantaneous mixing takes place in the confined volume.
- Q, R, and V remain constant
- Pressure in the confined volume remains constant and very near atmospheric pressure through the use of louvers or natural leakage.
- Gas entering from outside the confined volume is air with an oxygen concentration of 0.21 (21% by volume).

Case A: Ventilation fan(s) blowing into the confined volume.

The differential equation for the oxygen mass balance is

$$V\frac{dC}{dt} = 0.21Q - (R+Q)C$$

The solution for the boundary condition of C=0.21 at t=0 is

$$C_r(t) = \left[\frac{0.21}{Q+R}\right]\left[Q + \mathrm{Re}^{[-(Q+R)t/V]}\right]$$

Case B: Ventilation fans(s) drawing from the confined volume with the ventilation rate greater than the spill rate (Q>R).

The differential equation for the oxygen mass balance is

$$V\frac{dC}{dt} = 0.21(Q - R) - QC$$

The solution with the boundary condition of C=0.21 at t=0 is

$$C_r(t) = 0.21\left\{1 - \frac{R}{Q}\left[1 - e^{(-Qt/V)}\right]\right\}$$

Case C Ventilation fan(s) drawing from the confined volume with the ventilation rate less than or equal to the spill rate.

Differential equation for the oxygen mass balance is

$$V\frac{dC}{dt} = -RC$$

The solution with the boundary condition of C=0.21 at t=0 is

$$C_r(t) = 0.21e^{[-Rt/V]}$$

Case D After Release has ended

The oxygen concentration in the confined volume after the release has ended, Ce (t), can be approximated by one equation for all three cases.

The differential equation for the oxygen mass balance is

$$V\frac{dC}{dt} = 0.21Q - QC$$

The solution with the boundary condition of C=Cr (te) at t=te , where (t-te) is the time duration since the release ended is

$$C_e(t) = 0.21 - \left[0.21 - C_r(t_e)\right]e^{[-Q(t-t_e)/V]}$$

ODH Risk Assessment and Analysis
for
NSLS MER "A" Room (X17 Cryogenic system)

BACKGROUND

The X17 Cryogenic system has been operating since mid-80's. Numerous scientists, engineers and other technical staff contributed to its successful operation. An extensively well-written operation manual containing detailed description of the equipment, maintenance procedure and various alarm conditions routinely used by control room and other involved staff members.

Most commercially manufactured components were acquired as surplus from previously discontinued projects and are used after refurbishment. Therefore, associated safety features are in accordance with the manufacturer's specification at the time. The liquid helium and liquid nitrogen transfer lines were designed by NSLS and manufactured by commercial vendors. All these lines are equipped with standard safety features such as vacuum pump out ports and burst disks.

X17 cryogenic system is a helium closed loop cycle consists of a CTI Model 1430 Refrigerator/liquefier, two alternately used CTI Model RS Screw compressors, an external cryogenic purifier, a 1000 liter Hafman LHe dewar, a ~40,000 liters PEI liquid nitrogen storage tank, LN2/LHe shielded transfer lines, assorted instrumentations and control system. Please see the enclosed flow diagram shown of SLS 04.7-12-5C for more detail.

Helium gas is initially liquefied from room temperature and stored in a 1000 liter Dewar serving as a buffer storage tank for the wiggler magnet. Due to the inefficiency of the overall system, mainly the refrigerator, the buffer Dewar is normally kept at an average level of about 700 liters while the magnet is in operation. This scenario allows us to service the refrigerator quite often (at an average of about 8 to 10 week interval) by separating it cryogenically from the rest of the system. During this 48 hours period, the buffer Dewar will maintain the magnet at a liquid helium temperature while the refrigerator has been warmed up to the room temperature allowing a quick gas clean up and piston's o-rings replacement. A make-up and recovery system consisting of two commercial tanks located outside of the building serves as storage for make up and recovery helium gas. An excellent control micro maintains the system operating with minimum need for outside intervention. A combination of several automatic fill, relief valves and three triple loops MOORE type control systems constitutes the core of this system. Unscheduled down time is currently kept to minimum primarily due to existence of an excellent preventive maintenance program.

Summary descriptions of the components are:

Components			Manufacturer's Design Parameter				Equivalent @ STP		
Item	**Type**	**Vendor**	**Location**	**Qty.**	**Nom. Vol. (lit)**	**MAWP (PSIG)**	**Safety Features**	**Volume. (lit)**	**Flow Relief**
1	Tank	Trinity	Outside	2	283911	250 at 125˚F	Relief Valve	432725/ea.	Vendor Design
2	LHeDewar	Hoffman-Paul	MER "A"	1	1000	25 at 100 ˚F	Relief Valve	81000	Vendor's Design
3	LN2 Dewar	Process Engnr.	Outside	1	42866	66 at ~ 320˚F	Relief Valve	27434240	Vendor's Design
4	Refrg.	CTI	MER "A"	1	N/A				
5	Compr.	CTI	MER "A"	2	N/A				
6	Purif.	Cryanco	MER "A"	1					
7	Xline	Cryofab	MER "A"	~230ft	5	300/150/15	Burst Disk	405	Burst Disk

Mechanical Engineering Room "A" referred as MER "A", is a room with a partial mezzanine having the dimensions shown on enclosed sketch # 2, and mainly serves two functions. The first floor exclusively houses XI 7 cryogenic components along with two workbenches and few storage cabinets. The mezzanine accommodates experimental water system equipment and is monitored by NSLS utility group. There are two entrance/exit doors, one at each level, a roof top exhaust fan and a louvered window to the outside. The size and their capacity are described later.

DISCUSSION

The potential sources of reduced oxygen obviously are the unplanned discharge of the cryogens into the confined Space of MER "A". This analysis is primarily focused for the worst-case conditions, that is, the probability of an accidental release of cryogens from six major sources. 1) the LHe Dewar located inside of the room, 2) the liquid Nitrogen transfer line, partially inside of the room, 3-4) from make-up/recovery lines, 5) from interconnection GHe transfer pipe and, 6) from the liquid helium transfer lines due to rupture. However, analyses were also performed for other equipment failure cases as described later on.

The SBMS guidelines under subject area: Oxygen Deficiency Hazards (ODH), System Classification and Controls has been followed for this study.

OXYGEN DEFICIENCY HAZARD CALCULATIONS

ODH risk assessment estimates the fatality rate due to exposure to oxygen-deficient atmosphere. The level of risk depends on the nature of each operation. For a given operation several events may cause an oxygen deficiency. Each event has an expected rate of occurrence and each occurrence has an expected probability of causing a fatality. The oxygen deficiency hazard fatality rate is defined as:

$\Phi = \Sigma P_i F_i$ Where: Φ = the ODH Fatality rate (per hour)
P_i = the expected rate of the i^{th} event (per hour)
F_i = the fatality factor for the i^{th} event.

The values for F_i, the fatality factors, depend on the lowest oxygen concentration attained and depend on different conditions as described below (extracted from SBMS for later reference). The values for P_i, the expected failure rate of the i^{th} event (per hour) for affected equipment have also been extracted from SBMS.

Calculation of the Fatality Factor. F

All exposures to an O_2 concentration above 18% (137 mm Hg) are defined to be "safe" and to not contribute to a fatality; therefore the value of F is zero. That is, if the lowest attainable oxygen concentration is 18%, then the value of F is 10^{-7}. This value would result in one fatality in 10 million hours. An expected rate of occurrence of the event of 1 per hour would result in F=1. At decreasing O_2 concentrations, the value of F should increase until, at some point, the probability of fatality becomes unity. That point was selected to be 8.8% (67 mm Hg) oxygen, the concentration at which one minute of consciousness is expected.

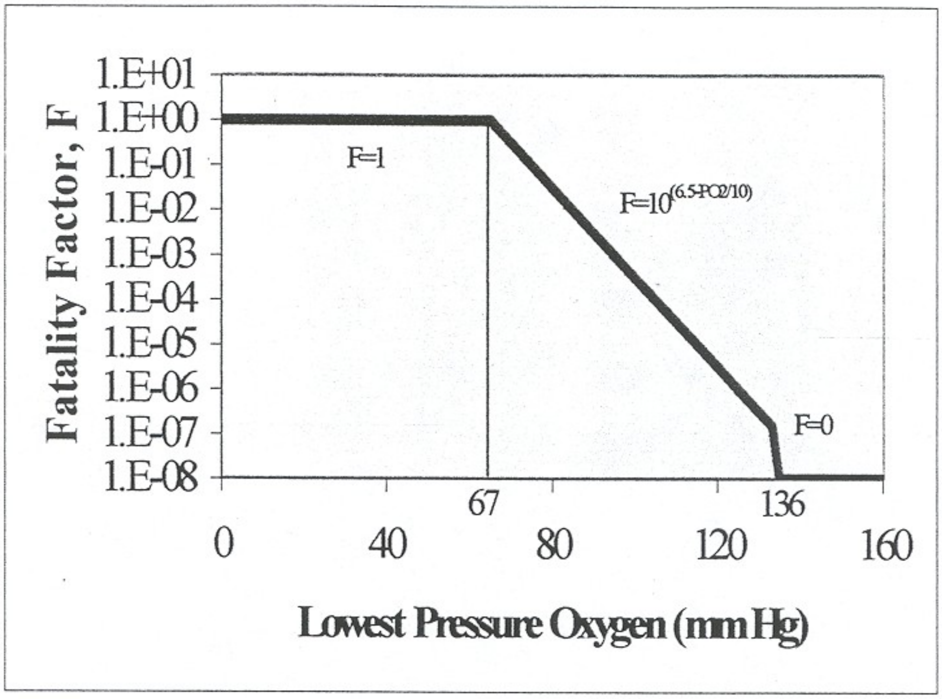


Figure A-1
Fatality factor (F_i) versus the lowest attainable oxygen concentration

The value of F depends on the oxygen concentration, the duration of exposure and the difficulty of escape. For convenience of calculation, Figure A-1 defines the relationship between the value of F and the lowest attainable oxygen concentration. This relationship should be used when no better estimate of the probability of fatality from a given event is available. The lowest concentration is used rather than an average.

Oxygen concentrations can be converted to partial pressures by, $Po_2 = CPa$

Where, C = oxygen concentration (volume %)
Po_2 = oxygen partial pressure (mm Hg)
Pa = atmospheric pressure (mm Hg)

ODH fatality rate for MER "A" room was calculated for various conditions where the Xl7 cryogenic system is in a fully operational mode. Spill rates from three major cryogen sources were calculated as shown below:

A. Spills from Liquid Helium Dewar caused by operation of its pressure relief system.

The dewar under study has a 1000 liter capacity and was built in 1966 by Hofman-Paul Cryogenic Division. The helium container is equipped with two Circle seal relief valves, a $^1/_2$ inch, in line and, another $^1/_4$ inch vent to atmosphere. Please see enclosed DWG # SLS-04.7-12-5C for detail flow diagram and safety features specification.

$V_{w\ Helium\ dewar}$	1000 liters = $1\text{x}10^6$ cc
P_{MWP} (Max working pressure)	25 psig = 40 Psia
P_{op} (Operating Pressure)	8 psig = 23 psia
P_{RP} (Relief Pressure) = Cracking pressure 13 + 20% over pressure for fully open	15 psig =30 psia
$D_{h\ 30}$ (Density, liquid helium @ 30 psia)	0.131 g/cc
$D_{h\ STP}$ (Density, GHe @ 1 atm & 300K)	$1.63\ \text{x}10^{-4}$ g/cc
M_H (Max Mass of helium @ 30 psia) = D_{h30} x $V_{W\ Dewar}$	0.131 g/cc x 10^6 cc = $1.31 \text{ x } 10^5$ g
$V_{H\ STP}$ (equivalent releasing volume) = M_H / $D_{H\ STP}$	$1.31 \text{ x } 10^5$g / $1.63 \text{ x } 10^{-4}$g/cc =$8.04 \text{ x } 10^8$ cc = $8.04 \text{ x } 10^5$ lit =28380 cf (maximum possible Volume)

Relief Valve Volumetric Flow rate:

The maximum flow rate of 5 scfm (air) when relief is fully opened is given by valve characteristic information. (Circle seal P/N 5159B-SMP-13)

Since relieved helium at the valve is in vapor form:

$D_{vapor\ helium\ at\ 4.2K}$ / $D_{gaseous\ helium\ at\ 300K}$ = .01639g/cc/. 0001625g/cc=100.9

Therefore: Spill equivalent rate for GHe @ 300 °K is: 5x100.9x2.69 (conversion factor from air to He)

$R_{Helium\ dewar}$ **=1357 SCFM**

B. Spills from Liquid Nitrogen Storage tank caused failure of its Transfer-line

An approximately 40000 liter capacity storage tank located at the north side of the NSLS building supplies LN2 to both the users and the X17 cryogenic system, please see the attached documents for detail. A $^1/_2$ inch vacuum jacketed transfer line supplies LN2 to a distributing manifold inside of the MER "A" room. There are two manual VJ valves, one serving as an isolation valve at the tank and the other serving as an isolation valve between users' fill station and MER "A". Therefore, it is conceivable to have a major spill from the portion of the transfer line that runs inside of the MER "A" before the distributing manifold. The volumetric flow rate is computed for the worst-case condition where maximum flow discharges from the inner transfer-line. For simplicity, the flow is assumed to be adiabatic and homogeneous where the two phases are treated as a single phase with suitably averaged fluid properties. Furthermore, the flow rate is calculated based mainly due to the pressure head (ignoring due to elevation and velocity heads). The applied formulas are extracted from **CRANE's** "Flow of Fluids, Technical paper No. 410."

Volumetric flow rate through LN2 transfer line in to the MER "A" is calculated by using the following formula:

$Q = 19.65\ d^2 \sqrt{h_L / K}$ (Eq. 3-19 CRANE)

Where:

Q = rate of flow, in gallons per minute

d = internal diameter of pipe, in inches

h_L = pressure head in feet of fluid

K = resistance coefficients

In this case:

d = .71 "(for $^1/_2$" schedule 5 pipe)

h_L =?

Δp = 43 psia (alarm level) - 14.7 = 28.3 psig = 4075 psf

γ_{LN2} = weight density of fluid, pounds per cubic ft

= 807 kg/m^3 x 2.2 lb/kg x (1m/3.28ft)^3 =50.33 pcf

$\therefore$ h_L = 4075 psf/50.33pcf = 81 ft of LN_2

$K = K_{\text{straight pipe}} + K_{90^\circ \text{ elbows}} + K_{\text{valves}}$

$K_{\text{straight pipe}} = f\,(L/D)$ where: f = friction factor
L = length of pipe, in ft
D = internal diameter of pipe, in ft

From Moody's chart f = .026 for D = .71"
L = 230 ft
D = .71/12 = .06ft

$\therefore$ $K_{\text{straight pipe}} = .026(230\text{ft}/.06\text{ft}) = 101$

$K_{90^\circ\text{ elbows}} = 12\ f_t\ N$ (from CRANE page A-29) for r (bending radius)/d= 1.5/. 7

Where: f_t=friction factor for fully turbulent flow
N = number of elbows =20

= 12 x .026 x 20 =6.3

$K_{\text{valves}} = 300\ f_t\ N$ (from CRANE page A-28)

= 300 x .026 x 2= 15.6

K =101+6.3+15.6 =123

$Q= 19.65\ (.71)^2\ \sqrt{81/123}$ = 8 gpm or 8 gpm x 0.13 cf/gpm = 1.05 cfm of LN2

$D_{\text{LN2 at 77.4 K}} / D_{\text{gaseous GN2 at 300 K}} \equiv 0.807$ g/cc/0.01142g/cc $\equiv$ 707

$\therefore$ $\underline{R_{\text{LN2 Storage tank}} = 1.05 \text{ X } 707 = 742 \text{ SCFM of GN2}}$

Check for the Reynolds number (R_e)

$R_e = 50.6\ Q\ \rho / d\ \mu$ (Eq. 3.3, CRANE)

ρ =weight density of fluid, pounds per cubic ft = 50.33 pcf

μ =absolute (dynamic) viscosity, in centipoises

= 158 x 10^{-6} Pa-Sec / 10^{-3} Centipoises/Pa-Sec = .158 Centipoises (Source: Cryogenic Systems by Randall Barron)
Or .165 Centipoises (from Bubble Chamber's Cryogenic Data Book)

R_e = (50.6 x 8 x 50.33) / (0.71 x .158) = 1.82 x 10^5 fully turbulent flow

C. Spills from failure of GHe make-up transfer tube to the storage tank.

Two medium sizes Trinity tanks parked at the north side of the NSLS building serve as the make-up and recover GHe to the liquefier. Please see the enclosed flow diagram, SLS-04.7-12-5C for detail inter-connection. Both tanks have ASME stamped relief valves and are kept at two different pressures known as high pressure (max. 250 psig) and low pressure (100 psig). Two half inch stainless steel tubes in conjunction with two control valves direct the flow of GHe between these tanks and the helium compressors located inside of the MER "A".

It is assumed that a failure in any one of these tubes could result in a GHe spill into the MER "A". The spill rate is calculated assuming isothermal compressible fluid at subsonic velocity using equation below: (Crane, Page A-14)

$q'_m = 678\ Y\ d^2\ \sqrt{\Delta P\ P_1' / K T_1 S_g}$ (Eq. 3-20, CRANE)

Where: q_m' = rate of flow, in cubic feet per minute at flow condition
Y = net expansion factor for compressible flow through orifices, nozzles, or pipe = .55 (conservative value, Crane A-22)
d = internal diameter, in inch = .5"
ΔP = differential Pressure, ~ 114.7-14.7 = 100 psig
P'_1 = Pressure, psia = 100 + 14.7 = 114.7 psia
K = resistance coefficient = f L/D = .028 x 200 /.042 = 133
f = friction factor ~ .028 for $^1/_2$ " tubing (from Moody's chart)
L/D = equivalent length of a resistance to flow, in pipe diameter
L = length of pipe in feet = 200 ft
D = internal diameter of pipe, in ft = 0.5/12 = 0.042 ft
T_1 = absolute temperature, in degree Rankine (460 + °F) ≈ 530 °
S_g = Specific gravity of gas relative to air = .1381 (CRANE, Page A-8)

$q' = 678 \times .55 \times 0.5^2\ \sqrt{100 x 114.7 / 133 x 530 x 0.1381}$

=101 cfpm

$R_{\text{GHe from Make-up}}$ = 101 SCFM, GHe

Mean flow Velocity V = q/A

$A = \pi \times d^2 / 4 = \pi \times (.5/12)^2 /4 = 0.00136\ ft^2$

V = 101 cfpm / .00136 sf = 74072 fpm or 74072/60 = 1234.5 fps

Maximum possible velocity (sonic) is expressed as:

$V_s = \sqrt{kgRT}$ (Eq. 3-8, CRANE)

Where: V_s = Sonic (or Critical) velocity of flow of gas, in fps

$K = C_p / C_y$ ratio of specific heats at constant pressure to constant volume
= 1.66 (CRANE, page A-8)
g = acceleration of gravity = 32.2 fpss
R = Gas Constant = 386.3 for helium
T = absolute temperature in degree Rankine = 530° R

$V_s = \sqrt{1.66x32.2x386.3x530}$ =3308 fps

Therefore, V =1234.5 fps < V_s =3308 fps, subsonic condition exist

D. Spills from failure of GHe recovery tube to the storage tank.

The recovery line transfers pressurized GHe to the storage tank mainly during warm-up. The line is subjected to the pressure level of the high-pressure tank whose relief valve is set at 250 psig. However, our maximum operating pressure has been <200 psig. An inline check valve is currently located inside MER A. Therefore, the pressurized portion between the check valve and the tank could conceivably develop leak. The following calculation is for the case where the line ruptures inside of MER A with high-pressure tank as its source. The following calculation is based on assumption of compressible fluids at subsonic velocity, which will be verified later in the calculation.

$q'_m = 678\ Y\ d^2 \sqrt{\Delta P\, P'_1 / K T_1 S_g}$ (Eq. 3-20, CRANE)

Where: q_m = rate of flow, in cubic feet per minute at flow condition

Y = net expansion factor for compressible flow through orifices, nozzles, or pipe = .55 (conservative value, Crane A-22)

d = internal diameter, in inches = .5"

ΔP = differential Pressure, ~ 260 - 14.7 ~ 245 psig

P_1 = Pressure, psia = 245 + 14.7 ~ 260 psia

K = resistance coefficient = f L/D = .028 x 200/. 042 =133

f = friction factor ~ .028 for $^1/_2$ " tubing (from Moody's chart)

L/D = equivalent length of a resistance to flow, in pipe diameter

L = length of pipe in feet = 200 ft

D = internal diameter of pipe, in ft = 0.5/12 = 0.042 ft

T_1 = absolute temperature, in degree Rankine (460 + 70°F) ≈ 530°

S_g = Specific gravity of gas relative to air = .1381 (CRANE, Page A-8)

$q'_m = 678x.55x0.5^2 \sqrt{245x260/133x530x0.1381}$

= 238scfpm

<u>$R_{\text{GHe from Recovery line}}$ =238 SCFM, GHe</u>

Mean flow Velocity V = q/A

$A = \pi \times d^2 / 4 = \pi \times (.5/12)^2 /4 = 0.00136 \text{ ft}^2$

= 238 cfpm/. 00136 sf = 175350 fpm or 175350/60 = 2922.5 fps

Therefore, V =2922.5 fps < V_s=3308 fps, subsonic condition exists.

The inline check valve will be re-located outside of MER, A which will eliminate the above condition.

E. Spills from interconnecting GHe transfer pipe (between compressor/liquefier and recovery valve)

The compressor when fully loaded is pumping GHe through a 1.5" diameter pipe at a pressure of about 245 psig through an external purifier to the liquefier. 1/ 2" diameter recovery line branches off from this line and connects to the GHe tank. Maximum flow of GHe through compressor is limited to the liquefier's liquefaction rate. At peak efficiency, this is equivalent to 25 liters per hour of liquid helium. Therefore, the equivalent released gaseous helium would be:

V (SCFM) =25 lit/hr x 810 V_{stp}/V_{liq} x 1 CF/28.32 lit x 1 hr/60 min = 12 SCFM

<u>$R_{\text{GHe from interconnecting pipe}}$ =12 SCFM, GHe</u>

This is considerably less than for the case "D."

E. Spills from liquid helium transfer lines due to rupture.

There are several interconnecting LHe transfer lines that are built by an outside vendor, Cryofab, according to the NSLS written specification. All these lines have a LN2 radiation shield and are equipped with a combination of vacuum pump out and burst port. The fill line between the storage dewar and the magnet has been used for this calculation case since it transfers the highest flow rate during the fill, nominally about 10 liters per minute. Flow rate for a homogeneous, single-phase liquid alone, possessing average fluid properties can be determined from:

$(\Delta p/\Delta L)_L = f\,(m'/A)^2 / 2\, g_c\, \rho_L\, D$ (Equation 7.60, R. Barron)

Where:

$\Delta p/\Delta L$ = pressure drop per unit length = (23 psia at dewar -14.7 psi at release)/in

=8.3 psia/in

f = friction factor ~ .028 for $^1/_2$" tubing (from Moody's chart)

m' = mass flow rate = lbm/sec

A = Cross-section area of the tube = $(.71)^2 \times \pi/4 = 0.04\ in^2$

g_c= Conversion factor = 1

ρ_L =liquid density = 124.8 g/lit x lb/454 g x 1 lit/61.02 in^3 = 4.512×10^{-3} lb/ in^3

D = tube inside diameter = .71"

L = length = an arbitrary of 60 in

8.3 lb/in = $0.028 \times (m'^2 /(.04\ in^2))^2 / (2 \times 1 \times 4.512 \times 10^{-3}\ lb/in^3 \times 0.71)$

8.3 = m'^2 17.5/ 0.00641 or m' = 0.0552 lbm/sec or 25.1 gm /sec

Or 25.1 gps x 60 = 1503 gpm /125 gpl = 12 lit/min

This result corresponds with our empirical value during the fill.

Assuming all this liquid turns into gaseous helium inside of the vacuum pipe and releases to the atmosphere through the pump-out/burst port. Therefore.

$D_{LHe\ at\ 4.2\ K\ \&\ 1\ atm} / D_{GHe\ at\ 300\ K}$ = 0.1248 g/cc/ 0.1625 g/cc = 770

or to an equivalent of 12 lit/min x 770 = 9230 ℓpm x 1 cf/28.32 lit = 326 scfpm

$\underline{R_{\text{GHe from LHe}} = 326 \text{ SCFM, GHe}}$

Check for subsonic condition:

For 0.75 " diameter of the release port where, $A = (.75/12)^2 \times \pi/4 = 0.0031 \text{ ft}^2$

V = 326 cfpm/.0031 sf = 106259 fpm or 1770 fps < V S = 3308 fps (subsonic condition)

Summary of calculated spill rates are:

$R_{\text{Helium dewar}}$ = 1357 SCFM, GHe (Case A)

$R_{\text{LN2 Storage tank}}$ = 1.05 x 707 = 742 SCFM, GN2 (Case B)

$R_{\text{GHe from Make-up}}$ = 10l SCFM, GHe (Case C)

$R_{\text{GHE FROM RECOVERY}}$ =238 SCFM, GHe (Case D)

$R_{\text{GHe from LHe}}$ = 326 SCFM, GHe (Case E)

Fan's exhaust capacity Q = 4073 CFM

Un-occupied space of the MER "A" = 11000 cf (please see enclosed the equipment room sketch)

Fatality factor calculation

Since ventilation rate is greater than any single spill rate (Q>R), corresponding case from SBMS guideline will be used to determine the fatality factor for each case.

The oxygen concentration with time is given by the equation:

$$C_r(t) = 0.21 \left[1 - (R/Q)(1 - e^{-Qt/V}) \right]$$

Where: $C_r(t)$ = Oxygen concentration @ time =t
R= Spill rate from each individual source, SCFM
Q = Ventilation rate, CFM = 4073 CFM
V = confined volume, ft^3 = 11000 CF (room volume minus estimated Equipment volume)
t = time, (minutes or seconds), beginning of release at t=o

Fatality factors due to spill from LHe (the largest) dewar is calculated as shown below for three intervals of one, five and steady state (∞) and for all other cases at t= ∞ (worst condition.)

Case A (LHe):

C_r(t=l MINUTE)=0.21 **[**1-(1357/4073)(1 - $e^{-4073 \times 1/11000}$)**]** = .21 [1-.333(1-.6905)]=0.188

18.8% (.188 x760= 143 mmHg) > 18 % (. 18 x 760= 137mm Hg)

$F(t = 1)=10^{(6.5\text{-po2}/10)}=10^{(6.5-143/10)}=0$

C_r(t=5MINUTE) = 0.21 [1-(1357/4073)(1-$e^{-4073x5/11000}$)**]** = .21 [1-333(1-.157)] = 0.151 15.1%

(.151 x 760= 115 mmHg) < 18 % (.18 x 760= 137mm Hg)

$F(t=5)=10^{(6.5\text{-pO}_2/10)}=10^{(6.5-115/10)}=1x10^{-5}$

C_r (t=**∞**) = 0.21 [1 - (1357/4073)(1 - 0)] = .21 [1-.333] = 0.14

14% (.14 x 760= 106 mm Hg) < 18% (.18x760= 137mm Hg)

$F(t=\infty)=10^{(6.5\text{-pO2}/10)}=10^{(6.5-106/10)}=7.94x10^{-5}$

Case B (LN2), (t=∞, worst condition):

C_r (t=∞)=0.21 [l-(R/Q)(l-0)]

C_r (t=∞) = 0.21 [1-(742/4073)] = .21 [1-.182] = 0.171

17.1% (.14 x 760= 130.5 mm Hg)< 18% (.18x760= 137mm Hg)

$F(t=\infty)=10^{(6.5\text{-pO2}/10)} = 10^{(6.5-130.5/10)} =2.8x10^{-7}$

Case C (Make-up), (t=∞, worst condition):

C_r(t=∞) = 0.21 [l-(R/Q) (l-0)]

C_r(t=∞) =0.21 [1-(101/4073)] = .21 [1- .025] = 0.205

20.5% (.205 x 760= 155.6 mm Hg)>18% (.18x760= 137mm Hg)

$F(t=\infty) =10^{(6.5\text{-pO2}/10)} = 10^{(6.5-155.6/10)} = 8.7 \text{ x } 10^{-10}$

Case D (Recovery), (t=∞, worst condition):

$C_r(t=\infty) = 0.21\ [1-(R/Q)\ (1-0)]$

$C_r(t=\infty) = 0.21\ [1-(238/4073)] = .21[1-.058] = 0.198$

19.8% (.198 x 760= 150.3 mm Hg)>18% (.18x760=137mmHg)

$F(t=\infty) = 10^{(6.5\text{-pO2}/10)} = 10^{(6.5-150.3/10)} = 2 \times 10^{-9}$

Case E (LHe transfer line), (t=∞, worst condition):

$C_r\ (t=\infty) = 0.21\ [1-(R/Q)\ (1-0)]$

$C_r(t=\infty) = 0.21\ [1 - (326/4073)] = .21\ [1- .08] = 0.193$

19.38% (.193 x 760 = 146.8 mm Hg) >18 % (.18x760= 137mm Hg)

F($t=\infty) = 10^{(6.5\text{-pO2}/10)}=10^{(6.5-146.8/10)}= 6 \times 10^{-9}$

The tabulated results of oxygen concentration and corresponding fatality factors for each source are listed below:

Source	time (minutes)	C(t)%	F(t)
LHe Dewar	1	18.8	0
(Thru ¼" RV)	5	15.1	1×10^{-5}
	∞	14	7.94×10^{-5}
LN2	∞	17.1	2.8×10^{-7}
Make-up	∞	20.5	8.7×10^{-10}
Recovery	∞	19.8	2×10^{-9}
LHe line	∞	19.3	6×10^{-9}
LHe Dewar	∞	7.5 (2613 SCFM)	1

The fatality factor is almost zero for all cases even without taking into account other natural ventilation sources, such as through two access doors and louvers because of the second level where personnel could be present at the time of occurrence.

EQUIPMENT FAILURE AND HUMAN ERROR RATES

The probabilities, P_i , for various failure modes along with their corresponding values (failure/hr) as given by SBMS are listed below. It should be noted that the larger values have been used when more than one estimate was given.

P_{LHeD} = Probability of Dewar rupture (relief opens) $1x10^{-6}$

P_{XLN2} = Probability of cryogenic fluid line leak/rupture $5x10^{-7}$

P_{XLHe} = Probability of cryogenic fluid line leak/rupture $5x10^{-7}$

P_{GHe} = Probability of pipe <3" rupture $1x10^{-9}$

P_{Comp} = Probability of Cryogenic compressor leak $1x10^{-6}$

P_{Gask} = Probability of Gasket leak $3x10^{-6}$

P_{FanM} = Probability of fan (motor) failure $1x10^{-5}$

P_{FanS} = Probability of fan flow switch failure $3x10^{-4}$

P_{Alarm} = Probability of Alarm failure $1x10^{-6}$

P_{Relief} = Probability of relief fail to open $1x10^{-5}$

P_{Power} = Probability of power failure $1x10^{-4}$

The failures cases considered are:

1) Normal Operation, helium Dewar relief valve opens, fan motor and fan flow switch or fan motor and alarm failure

$P_1 = P_{LHeD}\, P_{FanM}\, (P_{FanS} + P_{Alarm})$

$= (1 \text{ x } 10^{-6})(1 \text{ x } 10^{-5})[(3 \text{ x } 10^{-4}) + (1 \text{ x } 10^{-6})] = (1 \text{ x } 10^{-11})\,[\,3.01 \text{ x } 10^{-4}\,]$

$= 3.01 \times 10^{-15}$

2) Normal operation, LN2 lines develops major leak (including supply lines to the LHe shield lines, N=7), fan motor and fan flow switch or fan motor and alarm failure

$P_2 = N \times P_{XLN2}\ P_{FanM}\ (P_{FanS} + P_{Alarm})$

$= 7(5x\ 10^{-7})(1 \times 10^{-5})[(3 \times 10^{-4}) + (1 \times 10^{-6})] = 7\ (5 \times 10^{-12})[\ 3.01 \times 10^{-4}\ ]$

$= 1.05 \times 10^{-14}$

3) Normal Operation, GHe make-up line ruptures (<3"), fan motor and fan flow switch or fan motor and alarm failure

$P_3 = P_{XGHe}\ P_{FanM}\ (P_{FanS} + P_{Alarm})$

$= (1x\ 10^{-9})(1 \times 10^{-5})[(3 \times 10^{-4}) + (1 \times 10^{-6})] = (1 \times 10^{-14})\ [\ 3.01 \times 10^{-4}\ ]$

$= 3.01 \times 10^{-18}$

4) Normal Operation, GHe Recovery line Ruptures (<3"), fan motor and fan flow switch or fan motor and alarm failure

$P_4 = P_{XGHe}\ P_{FanM}\ (P_{FanS} + P_{Alarm})$

$= \mathbf{P_3} = 3.01 \times 10^{-18}$

5) Normal Operation, LHe transfer line ruptures (N=5), fan motor and fan flow switch or fan motor and alarm failure

$P_5 = N \times P_{XLHe}\ P_{FanM}\ (P_{FanS} + P_{Alarm})$

$= 5\ (5 \times 10^{-7})(1 \times 10^{-5})[(3 \times 10^{-4}) + (1 \times 10^{-6})] = 5(5 \times 10^{-12})\ [\ 3.01 \times 10^{-4}\ ]$

$= 7.53 \times 10^{-15}$

6) System in use, LHe Dewar relief opens (case A with highest fatality of 7.94×10^{-5}) and power failure

$P_6 = P_{LHeD}\ P_{power}$

$= (1 \times 10^{-6})(1 \times 10^{-4}) = 1 \times 10^{-10}$

7) Normal Operation, helium Dewar relief valves open (assume fatality factor one for maximum spill rate), fan motor and fan flow switch or fan motor and alarm failure

$P_7 = P_{LHeD}\ P_{FanM}\ (P_{FanS} + P_{Alarm})$

$= (1 \times 10^{-6})(1 \times 10^{-5})[(3 \times 10^{-4}) + (1 \times 10^{-6})] = (1 \times 10^{-11})\ [\ 3.01 \times 10^{-4}\ ]$

$= 3.01 \times 10^{-15}$

The tabulated results of oxygen concentration and corresponding fatality factors for each individual source along with their corresponding probabilities failure are listed below:

Source	time (minutes)	C_r (t)%	F_i	P_i
LHe Dewar	1	18.8	0	
(Thru ¼" RV)	5	15.1	1×10^{-5}	
	∞	14	7.94×10^{-5}	3.01×10^{-15}
LN2	∞	17.1	2.8×10^{-7}	1.505×10^{-14}
Make-up	∞	20.5	8.7×10^{-10}	3.01×10^{-18}
Recovery	∞	19.8	2×10^{-9}	3.01×10^{-18}
LHe line	∞	19.3	6×10^{-9}	7.53×10^{-15}
LHe Dewar	∞	7.5	1	$1. \times 10^{-15}$

The fatality factor is almost zero for all cases even without taking into account the existence of other natural ventilation sources, such as two access doors and louvers because of the second level where personnel could be present at the time of occurrence.

Fatality Rate Calculation

The fatality rate, Φ, is the summation of the products of probability and fatality factors for all events as described earlier. Fatality factors values for t=∞ is used to obtain the total fatality rate. F6 is assumed to be equal F5.

$\Phi = \Sigma P_i F_i, = P_1F_1 + P_2 F_2 + P_3F_3 + P_4F_4 + P_5F_5 + P_6F_6 + P_7F_7$

$= (3.01 \times 10^{-15})(7.94 \times 10^{-5}) + (1.05 \times 10^{-14})(2.8 \times 10^{-7}) + (3.01 \times 10^{-18})(8.7 \times 10^{-10}) +$

$(3.01 \times 10^{-18})(2 \times 10^{-9}) + (7.53 \times 10^{-15})(6 \times 10^{-9}) + (1 \times 10^{-10})(7.94 \times 10^{-5}) + (3.01 \times 10^{-15})(1)$

$= 2.39 \times 10^{-19} + 2.94 \times 10^{-}21 + 2.62 \times 10^{-}27 + 6.02 \times 10^{-27} + 4.52 \times 10^{-23} + 7.94 \times 10^{-15}$

$+ 3.01 \times 10^{-15}$

$= 1.095 \times 10^{-14} < 10^{-7}$

Since ODH class zero is defined as when $\Phi < 10^{-7}$ (from SBMS guideline), the MER "A" falls into ODH class zero under conditions considered.

Conclusion

A subsequent analysis was conduced to investigate the adequacy of the LHe relief system (see the X17LheRelief.doc). The maximum volumetric flow rate based on assumptions described in the before mentioned document was found to be 2613 SCFM or 1256 SCFM (92%) above spill rated of 1357 SCFM from Dewar's originally installed relief valve. As a result an additional ½" Kunkle relief valve and two ½" redundant burst disks were installed in parallel with ¼" RV (see the Dewar's relief PID). An installed exhaust pipe directs all released helium gas to the outside building (please see the flow diagram). Note that an additional failure case with fatality factor of one (worst case condition) was included in this analysis to account for maximum spill rate from all LHe Dewar relief systems (case number seven).

Ceck for no Back Pressure on the exhaust pipe

A 4" nominal PVC pipe with an overall length of about 14 ft has been installed to direct the discharged gaseous helium from LHe Dewar RV/burst disk to the outside of MER "A" room. Following calculation has been carried out to insure that no backpressure will hinder the flow of gaseous helium through the pipe.

Same equation as for the case "C" is used to verify the flow state under these boundary conditions. Again, it is assumed isothermal (exhaust vapor helium will wormed up to room temp as it passes through metal aluminum pipe) compressible fluid at subsonic velocity.

$q'_m = 678\ Y\ d^2 \sqrt{\Delta P\ P_1' / K T_1 S_g}$ (Eq. 3-20, CRANE, papge A-14)

Where: q_m' = rate of flow, in cubic feet per minute at flow condition
Y = net expansion factor for compressible flow through orifices, nozzles, or pipe = .55 (conservative value, Crane A-22)
d = internal diameter in inch (for 4" pipe with .125" wall) = 3.75"
ΔP = differential Pressure, ~ 30 -14.7(1 atm) ~= 15 psig
P'_1 = Pressure, 30 psia (see table for case A)
K = resistance coefficient = f L/D = .016 x (14 / .3125) = .717
f = friction factor ~ .016 for 3.75" ID (from Moody's chart)
L/D = equivalent length of a resistance to flow, in pipe diameter
L = length of pipe in feet = 14 ft
D = internal diameter of pipe, in ft = 3.75/168 = 0.3125 ft
T_1 = absolute temperature, in degree Rankine
Assumed mean temp between inlet and outlet (4.2Kx 1.8 + 530)/2≈270
S_g = Specific gravity of gas relative to air = .1381 (CRANE, Page A-8)

$q' = 678 \times .55 \times 3.75^2 \sqrt{15x30/0.717x270x.01381}$

≈ 181886 cfpm > 2613 SCFM, release rate as shown for LHe relief size calculation, therefore no flow restriction will occur.

Mean flow Velocity V = q/A

$A = \pi \times d^2 / 4 = \pi \times (3.75/12)^2 /4 = 0.08\ ft^2$

V = 2613 cfpm / .08 sf = 34068 fpm or 34068/60 = 567 fps

Maximum possible velocity (sonic) is expressed as:

$V_s = \sqrt{kgRT}$ (Eq. 3-8, CRANE)

Where: V_s = Sonic (or Critical) velocity of flow of gas, in fps
$K = C_p / C_y$ ratio of specific heats at constant pressure to constant volume = 1.66 (CRANE, page A-8)
g = acceleration of gravity = 32.2 fpss
R = Gas Constant = 386.3 for helium
T = absolute temperature in degree Rankine = $270^\circ R$

$V_s = \sqrt{1.66x32.2x386.3x270} = 2361$ fps

Therefore, V <<<$V_{s,}$ subsonic condition exists.

Control Measures:

ODH control measures for class zero requires warning signs in the affected area and ODH training for all affected personnel. NSLS has implemented additional measures in order to further enhance the safety operation and to provide un-interrupted beam from the X17 wiggler magnet to three beam lines users. This includes, installation of a double O_2 monitoring sensors (GASTECH # Sate T Net 200) inside of the MER "A" where one sensor is mounted at 3 ft below ceiling level and the other at 3 ft above floor level. The sensors are interlocked to the ceiling fan switch, to the first floor louvers, to three strobe lights,- two mounted on the inside, one at the main entrance door and to the control room alarm micro alarm system. A comprehensive preventive maintenance and interlock functional test is in place as described in the document entitled " Preventive Maintenance and Interlock Test Procedure, LS-M-310".

ODH Risk Assessment and Analysis

for

(The NSLS west roll-up door's buffer area)

Background

This area consists of two roll-up doors, along with two single hinged doors for entry and exit to the x-ray experimental floor. There is in essence a buffer area between these two doors where the LN_2 fill station is located and which the beam line personnel use to fill their portable Dewar (normally around 100 to 200 liters capacity). The empty helium Dewar also is dropped off in this buffer area for pick up by the outside suppliers. In addition, there is also a single double hinge access door to an adjacent room.

The liquid nitrogen supply line is terminated inside of the buffer area with a manual shut off valve. There are several relief valves in between the shut-off valves as shown on the accompanying schematic flow diagram. Users routinely fill their Dewar by following instructions provided to them by the NSLS personnel.

These subject areas are equipped with the following signs and monitoring equipments.

I. Inside the buffer area: 1. An Oxygen sensor is mounted on the wall directly above the fill station at about 9.3 feet from floor level (7 feet from ceiling). 2. Two large strobe beacon lights one placed above entry door to the experimental area and the other mounted directly above the fill station. 3. A 90 db audible horn.

II. At entry door from the experimental area. 1. A posted caution sign indicating "Oxygen Deficiency Hazard when Beacon Illuminated or alarm sounding, Do Not Enter". 2. A large strobe light mounted at an accessible level next to the entry door. 3. O_2 electronic monitoring unit mounted on the wall next to the entry door equipped with a backup battery to sustain both the sensor and the monitor operational during a power surge.

III. At the entry from outside door. 1. A posted caution sign indicating "Oxygen Deficiency Hazard when Beacon Illuminated or alarm sounding, Do Not Enter". 2. A large strobe light mounted directly above the door.

The O2 monitor is read back to the NSLS Control Room and is interlocked to an inline solenoid shut-off valve and the motor that opens the large roll-up door.

Discussion

The potential source of reduced oxygen in this area will be the continuous discharge of liquid nitrogen. The solenoid valve, located outside of the room, is normally closed as well as a manual shut off valve located inside. A safety relief valve and a pressure gauge are located in between these valves. The worst case scenario would be when both of these valves are in an open position and the flow of liquid nitrogen is spilled into the area. This condition is highly unlikely, but an analysis similar to the MER "A" is carried out resulting in **NO** ODH risks as defined in the SBMS ODH subject area.

Oxygen Deficiency Hazard Calculation (As defined by SBMS)

ODH risk assessment estimates the fatality rate due to exposure to oxygen-deficient atmosphere. The level of risk depends on the nature of each operation. For a given operation several events may cause an oxygen deficiency. Each event has an expected rate of occurrence and each occurrence has an expected probability of causing a fatality. The oxygen deficiency hazard fatality rate is defined as:

$\Phi = \Sigma P_i F_i$ Where: Φ = the ODH Fatality rate (per hour)
P_i = the expected rate of the i^{th} event (per hour)
F_i = the fatality factor for the i^{th} event.

The values for F_i, the fatality factors, depend on the lowest oxygen concentration attained and depend on different conditions as described below (extracted from SBMS for later reference). The values for P_i, the expected failure rate of the i^{th} event (per hour) for affected equipment have also been extracted from SBMS.

Calculation of the Fatality Factor. F

All exposures to an O_2 concentration above 18% (137 mm Hg) are defined to be "safe" and to not contribute to a fatality, therefore the value of F is zero. That is, if the lowest attainable oxygen concentration is 18%, then the value of F is 10^{-7}. This value would result in one fatality in 10 million hours. An expected rate of occurrence of the event of 1 per hour would result in F=1. At decreasing O_2 concentrations, the value of F should increase until, at some point, the probability of fatality becomes unity. That point was selected to be 8.8% (67 mm Hg) oxygen, the concentration at which one minute of consciousness is expected.

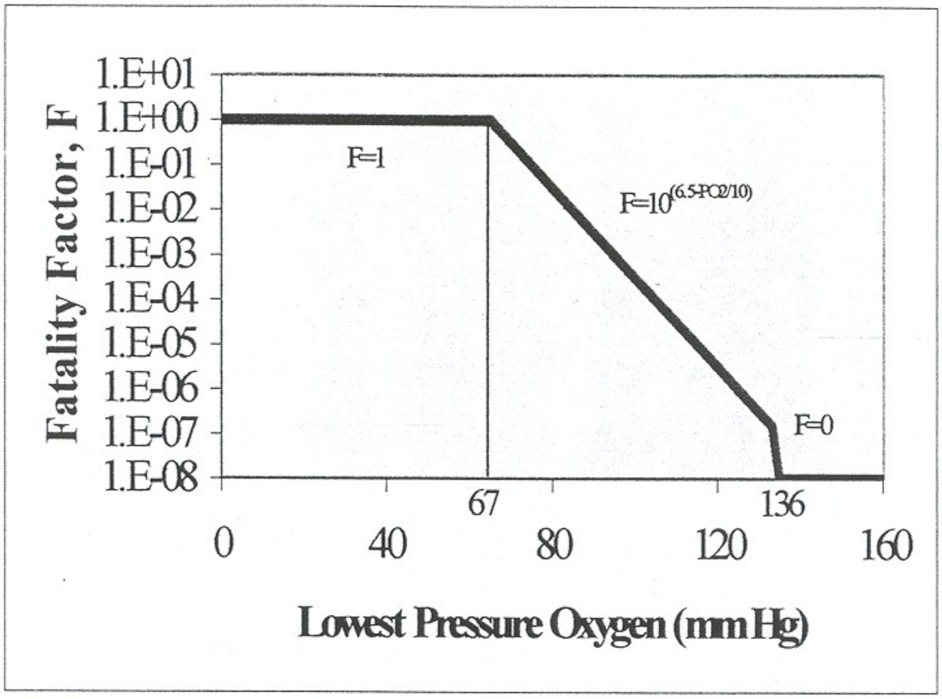


Figure A-1
Fatality factor (F_i) versus the lowest attainable oxygen concentration

The value of F depends on the oxygen concentration, the duration of exposure and the difficulty of escape. For convenience of calculation, Figure A-1 defines the relationship between the value of F and the lowest attainable oxygen concentration. This relationship should be used when no better estimate of the probability of fatality from a given event is available. The lowest concentration is used rather than an average.

Oxygen concentrations can be converted to partial pressures by, $Po_2 = CPa$

Where, C = oxygen concentration (volume %)
Po_2 = oxygen partial pressure (mm Hg)
Pa = atmospheric pressure (mm Hg)

A. Spills from Liquid Nitrogen Storage tank caused by LN2 Transfer-line

The volumetric flow rate is computed for the worst case scenario where maximum flow discharges from the inner transfer-line to the open space area. For simplicity, the flow is assumed to be adiabatic and homogeneous where the two phases are treated as a single phase with suitably averaged fluid properties. Furthermore, the flow rate is calculated based mainly due to the pressure head (ignoring both the elevation and velocity heads). The applied formulas are extracted from **CRANE's** "Flow of Fluids, Technical paper No. 410."

Volumetric flow rate through LN2 transfer line can be estimated by using the following expression.

$Q = 19.65\ d^2\ \sqrt{h_L / K}$ (Eq. 3-19, CRANE)

Where:
Q = rate of flow, in gallons per minute
d = internal diameter of pipe, in inches
h_L = pressure head in feet of fluid
K = resistance coefficients
ρ = density, g/cc
γ = weight density of fluid, pounds per cubic ft

In this case:

d = .71 "(for ½" schedule 5 pipe)

h_L = ?

Δp = 43 psia (alarm level) - 14.7 = 28.3 psig = 4075 psf

γ_{LN2} = weight density of fluid, pounds per cubic ft

= 807 kg/m^3 x 2.2 lb/kg x (1m/3.28ft)^3 =50.33 pcf

∴ h_L = 4075 psf/50.33pcf

= 81 ft of LN2

$K = K_{\text{straight pipe}} + K_{90^\circ \text{ elbows}} + K_{\text{valves}}$

$K_{\text{straight pipe}} = f\,(L/D)$ where: f = friction factor
L = length of pipe, in ft
D = internal diameter of pipe, in ft

From Moody's chart
f = .026 for D = .71"
L = 84 ft
D = .71/12 = .06ft

∴ $K_{\text{straight pipe}}$ = .026(84ft/.06ft) = 36

$K_{90^\circ \text{ elbows}} = 12\ f_t\ N$ (from CRANE page A-29) for r (bending radius)/d

= 1.5/. 7

where: f_t=friction factor for fully turbulent flow
N = number of elbows =20

= 12 X .026 X 20 =6.3

$K_{valves} = 300\ f_t\ N$ (from CRANE page A-28)

= 300 X .026 X 2= 15.6

K =36+6.3+15.6 =58

$Q = 19.65\ (.71)^2\ \sqrt{81/58}$ = 11.72 gpm or 11.72 gpm x 0.13 cf/gpm
= 1.52 cfm of LN2

$\rho_{\text{LN2 at 77.4 K}} / \rho_{\text{gaseous GN2 at 300 K}} \equiv 0.807\ \text{g/cc}/0.01142\text{g/cc} \equiv 707$

Therefore, the spills from liquid Nitrogen storage tank through its transfer line is:
$\mathbf{R}_{\textbf{LN2 Storage tank}}$ $\underline{= 1.52 \text{ X } 707 = 1075 \text{ SCFM of GN2}}$

Confined Volume

Un-occupied buffer space between two west roll-up doors ~ 6000 cf (18'W,22'L,16'H)

Exhaust System: Interlocked entry/exit roll-up door (12' W x 16' H)

Oxygen Concentration Analysis

We apply the case for a confined volume, without an active ventilation (i.e. fan) to calculate time taken to reduce the oxygen concentration 18% as shown below:

$C_r(t) = 0.21\ e^{-Rt/v}$ Case "C" from SBMS web page (oxygen concentration in ventilated spaces)

Where: Cr(t) = Oxygen Concentration during release
R= Spill rate into confined volume (SCFM)
t= time (minute) beginning of release is at t=0
V= Confined volume, (CF)

We now calculate elapse time (from zero) when Oxygen concentration begins to fall to below 18% by volume (ODH threshold)

$0.18 = 0.21\ e^{-(1075(t)/6000}$

t = 0.86 minute

This indicates that the fatality factor will begin to rise after 0.86 minutes, after start of spill if the entry/exit door fails to open.

We assume the worst case condition when the fatality factor=1 (i.e. oxygen concentration to equal or less than 8.8% by volume as defined by SBMS guide line).

Equipment Failure and Human Error Rates

The probabilities, Pi , for various failure mode along with their corresponding vlues (events/hr) as given by SBMS web page "equipment Failure Rate Estimates" are listed below. The larger values have been used when more than one estimate was given.

P_{LN2} = Probability of cryogenic fluid line leak/rupture, $5x10^{-7}$

P_A = Probability of alarm failure, $1x10^{-6}$

P_P = Probability of power failure, $1x10^{-4}$

P_M = Probability of exit door's electric motor fails to run, $3x10^{-4}$

P_S = Probability of Solenoid valve fail to operate, $1x10^{-3}$

The Failure Cases considered are:

1. System in use, LN2 transfers line leak/rupture and alarm failure.

   $P1 = (P_{LN2})(PA) = (5x10^{-7})(1x10^{-6}) = 5x10^{-13}$

2. System in use, LN2 transfers line leak/rupture and power failure.

   $P2 =(P_{LN2})(P_P) = (5x10^{-7})(1x10^{-4}) = 5x10^{-11}$

3. System in use, LN2 transfer line leak/rupture and door fails to open due to electric motor fails to run.

   $P3 = (P_{LN2})(P_M) = (5x10^{-7})(3x10^{-4}) = 1.5x10^{-11}$

4. System in use, LN2 transfers line leak and the Solenoid valve failed to operate (close) while the manual valve is open.

   $P4 = (P_{LN2})(P_S) = (5x10^{-7})(1x10^{-3}) = 1.5x10^{-10}$

Fatality Rate Calculation

The fatality rate, Φ, is the product of the combined failure rates and the fatality factor for each failure. Since we set the fatality factor to unit (F=1) for all cases,

$\Phi = \sum PiFi = \sum Pi = P1 + P2 + P3 + P4 = (5x10^{-13}) + (5x10^{-11}) + (1.5x10^{-11}) + (5x10^{-10})$

$\Phi = 5.66x10^{-10}$

With the control measures described below, this area presents no ODH risks as indicated in the SBMS ODH Subject Area.

"Areas that have Department/Divisional controls established that can demonstrate the fatality rate is less than 10^{-9} by engineering/safety analysis, may not have to have an ODH classification (SME concurrence required)".

Control Measures

An ODH sensor interlocked to a visual and audible alarms in the area with a read back to the NSLS Control Room and interlocked to an inline solenoid shut-off valve and the motor that opens the large roll-up door. Adequate posting to direct personnel actions should the alarm system activate.

Prepared By: Andrew Ackerman	Approved By: Andrew Ackerman	Approved By: Randy Church

*Approval signatures on file with master copy.

1.0 PURPOSE

This document is to define the NSLS Oxygen Deficiency Hazard (ODH) alarm systems and the Operations Group response to alarms from these monitoring systems.

2.0 SCOPE

The requirements outlined here apply to the following NSLS ODH alarm systems:

- Liquid Nitrogen Fill Station
- MER A
- LEGS Cryolab

3.0 RESPONSIBILITY

Users/NSLS Staff are to report all alarms to the NSLS Control Room and, if appropriate, to BNL Emergency Services.

NSLS ES&H Staff are to analyze and assure adequate control of ODH risks.

NSLS Operations Staff are to monitor and respond to alarms as outlined in this document.

NSLS Mechanical Engineering Staff are to maintain the ODH detection systems in operating and calibrated order.

4.0 ODH DETECTION EQUIPMENT SUMMARY

The details of the oxygen sensing, alarms, and postings are presented in the tables contained in the attachment below. All NSLS ODH monitoring systems alarm when the ambient oxygen concentration falls below 19.5% and reset if the oxygen concentration returns to 19.5% or greater.

Equipment Matrix

5.0 ALARM RESPONSE

In responding to an alarm, the first priority of the Operations Coordinator is to reduce or eliminate the potential for harm to individuals. The Operations Coordinator shall take no action that places him/her or other personnel in danger.

The Operations Coordinators are NOT emergency response personnel. No non-emergency personnel may enter an ODH area once an ODH alarm has sounded without assistance from BNL Emergency Services Personnel.

If an ODH alarm is received in or reported to the NSLS Control Room, an Op Co should proceed to the area to investigate and determine if anyone needs assistance and the Machine Operator should call BNL Emergency Services for their assistance. **The Op Co is not to enter any ODH area once an alarm has sounded, even if the alarm resets.** The Op Co is to remain on the scene to assist emergency personnel in interpreting the sensor readouts, to explain the systems, and to assure no personnel entry without assistance from BNL Emergency Services

6.0 GUIDANCE

When responding to ODH alarms at the NSLS, BNL Emergency Services may not be familiar with the NSLS detection and control systems. The Op Co on the scene can provide valuable information towards determining the nature of the alarm and the operation of the control systems. Some guidance follows.

6.1 **Liquid Nitrogen Fill Station (West Roll-Up Door).** An ODH Alarm from this area should also trigger the opening of the large West Roll-Up door. Once the door opens, the alarm is expected to reset in a few minutes time. With the door open, and the alarm reset for 10 minutes or more with the readout consistently showing greater than 19.5% Oxygen concentration, it is reasonable to expect that the hazard has cleared.

6.2 **MER A.** An ODH alarm from this area should activate the fan system described in the attachment above. An observer standing outside this room can see the intake louvers open, but can not readily determine of the fans have activated. As we have two sensors in this room, one at the upper level and one at the lower level of the room, having both readouts indicate that the Oxygen concentration is greater than 19.5% is good indication that the hazard has cleared. There is no manual switch to activate the fan and louvers, only the Oxygen sensors can trigger those systems.

6.3 **LEGS Cryolab.** An ODH alarm from this area should activate the fan systems described in the attachment above. An observer standing outside this room can easily determine of the fans are on by the distinctive noise they make. These are high volume fans expected to clear any ODH hazard in a few minutes time.

If the alarm resets, the fans will turn off. There is switch in the LEGS Target Room (adjacent to the Cryolab) that can be set to have the fans stay on regardless of the Oxygen concentration. When responding to an alarm in this area, it is best to activate the fans in this manual mode to keep them activated until the trouble has been resolved.

Prepared By: Payman Mortazavi	Approved By: Scott Buda	Approved By: Andrew Ackerman

*Approval signatures on file with master copy.

1.0 PURPOSE

This procedure is to provide requirements for the calibration, maintenance, and interlock system testing associated with the NSLS Oxygen sensors.

2.0 SCOPE

The requirements outlined in this procedure pertain to all Oxygen sensors in use at the NSLS. The location and type of monitor in use are listed in the table below. The Thermo Electron Corporation formerly as GASTECH manufacturer of all the NSLS Oxygen sensors.

LOCATION	SERIAL #	SENSOR'S TYPE
WEST ROLL UP DOOR, 151A	0043172	Safe T Net 100
X17 CRYO RM MER 'A'	9935097	Safe T Net 210
X5 LEGS, 1-169	0043169	Safe T Net 100

3.0 RESPONSIBILITY

3.1 Responsible system engineer: The NSLS mechanical engineer assigned responsibility for the Oxygen sensors and interlocked systems will assure that the systems remain calibrated, maintained, and tested as outlined in this procedure. He/She will track the required weekly and monthly testing schedule and assure timely completion of the required tests.

3.2 NSLS QA Representative: The NSLS QA Representative will assure that the quarterly and annual maintenance and testing schedule is tracked and will provide notice of these requirements to the Responsible System Engineer.

3.3 NSLS interlock engineer: The NSLS interlock will provide maintenance and engineering support as required.

3.4 NSLS ES&H Staff: The NSLS ES&H Staff will provide guidance and approval for the design, operation, maintenance, and testing of the Oxygen sensor system and alarms.

4.0 SYSTEM DESCRIPTION

4.1 Alarm States

The GASTECH O_2 monitors have the following alarm states:

Normal Operational State: Pilot light on, no audible indication, Oxygen level (20.9% O_2) is indicated on the screen. This indicates normal Oxygen levels in the area

Warning State: Warn Light on, Pilot light off, Pulsing audible tone, Oxygen level of 19.9% or less is indicated on the screen. The oxygen level has decreased to a below normal state (19.9% O_2 or less). This will warn all occupants in the area that a potential ODH environment may exist.

Alarm State: Alarm Light on, Pilot light off, Pulsing audible tone, Oxygen level of 19.5% or less is indicated on the display screen. The Oxygen level has decrease to 19.5% or less. This will warn all occupants in the area that an ODH environment does exist.

Fail State: Fail Light on. Display screen flashes, Steady audible tone. This will alert all occupants in the area that the monitor has failed.

Over Range: Alarm light on, Pilot light off, Pulsing audible tone, and Oxygen level of 30% is displayed on a flashing screen. This will warn all occupants that an oxygen rich, explosive environment exists.

Summary of the Alarm Indications

Condition	O2 Level	Cause	Visual Indication	Audible Indication
Normal	20.9%	Start-up complete	PILOT light on	None
Warn	19.9%	Decreasing reading Past alarm level	WAR light on	Pulsing tone
Alarm	19.5%	Decreasing reading Past alarm level	ALARM light on	Pulsing tone
Fail	<0	Below zero reading Hardware problem	FAIL light on Display reading Flashes	Steady tone
Over Range	30%	Excessive Oxygen Condition, Incorrect span or zero potentiometer adjustment	ALARM light on, Display reading flashes	Pulsing tone

4.2 Hardware Action

The following automatic actions occur when any of the alarm states occur.

4.2.1 West Roll-up Door. (Area 1-151):

4.2.1.1 Control room alarm.

4.2.1.2 The outer Roll-up door opens.

4.2.1.3 The automatic isolation valve at the liquid nitrogen fill station closes.

4.2.1.4 The Warning Lights at the three entry points to the room are lighted.

- Inside the inner access door.
- Outside the outer access door.
- Inside the door from room 1-151.

4.2.2 X17 Cryogenic room (MER-“A”):

4.2.2.1 **C**ontrol room alarm.

4.2.2.2 Ceiling Exhaust fan turns on.

4.2.2.3 Intake air Louvers open~~s~~.

4.2.2.4 Inside warning strobe light is lighted.

4.2.2.5 Outside warning strobe light at the entry point to the room is lighted.

4.2.2.6 Inside audible alarm turns on.

4.2.3 Rm. 1-169 (ME-049, X5):

4.2.3.1 Control room alarm

4.2.3.2 Exhaust fan 725F1-EXHF168 turns on. (Between 1-168 & 1-169)

4.2.3.3 Exhaust fan 725RO-EXHF169 turns on. (From 1-169 to roof)

4.2.3.4 Louver for fan 725RO-EXHF169 opens.

4.2.3.5 The inside beacon lights.

4.2.3.6 The outside beacon lights.

4.2.3.7 The inside audible alarm turns on.

5.0 CALIBRATION AND TESTING

This section describes preventive and corrective maintenance procedures for O_2 monitors. This schedule describes weekly, monthly, quarterly, and annual procedures to ensure the monitor's performance and durability.

Whenever an oxygen sensor is replaced, systems interlocked to that sensor must be tested and re-certified as described below.

<u>REQUIRED EQUIPMENT:</u>

Electric Multi-Meter.

GASTECH Calibration gas cylinders

Perform the following tasks on each of the monitors.

5.1 Weekly Operational Check.

5.1.1 Check that the Pilot Light is on.

5.1.2 Check that the Display is reading 20.9% ±0.2%.

5.1.3 Record the findings on the "NSLS: O2 Monitor Weekly Preventive Maintenance Schedule.

5.2 Monthly Operational Check.

5.2.1 Notify the Control Room that the monitor will be checked for proper operation and that the alarms will be activated.

5.2.2 Check that the Pilot Light is on.

5.2.3 Observe and record the original oxygen level reading.

5.2.4 Feed GN2 from test kit bottle into the openings of the sensor's housing.

5.2.5 Confirm that the reading on the display screen decreases while performing .2.4.

5.2.6 Continue feeding GN2 into the sensor housing until the oxygen level falls below the warning and alarm set points and activates the appropriate automatic actions (fans, etc).

5.2.7 Stop GN2 feeding into the sensor housing and confirm that the oxygen level reading returns to the original reading and all automatic actions return to normal.

5.2.8 Record all findings on the "NSLS: O_2 Monitor Monthly Preventive Maintenance Schedule".

5.3 Quarterly Calibration for GASTECH Safe T Net 100.

5.3.1 Notify the Control Room that the unit is being calibrated and all related alarms will be activated.

5.3.2 Verify that the unit is reading normal oxygen levels (20.9%) and all indications and automatic actions are in a normal state.

5.3.3 Unscrew the cover from the transmitter housing (no action is needed with the controller).

5.3.4 Set the multi-meter to read in a range of 100 to 500 mV DC and connect the positive lead to the white test jack and the negative lead to the blue test jack located inside of the transmitter housing.

5.3.5 Connect the 100% nitrogen cylinder to the sensor housing using the supplied connection cup and hose. Open the cylinder valve slowly (ideally adjust it to a 1.0 SCFH flow rate if a flow meter is available).

5.3.6 Observe the reading on the multi-meter and on the display screen. The multi meter should read 100 mV DC to correspond with the display reading of 0.0%. If necessary adjust the “Zero” potentiometer located inside of the transmitter so that the display reads 0.00%. (Clockwise increases, Counter-clockwise decreases).

5.3.7 Close the valve and remove the 100% nitrogen cylinder from the sensor housing.

5.3.8 Connect the 20.9% oxygen cylinder to the sensor housing; open the cylinder valve slowly (ideally adjust it to a 1.0 SCFH flow rate if a flow meter is available). If necessary, adjust the “Span” potentiometer located inside of the transmitter to 379 mV, which corresponds to 20.9%. (Clockwise increases, Counter-clockwise Decreases)

5.3.9 Close and remove the 20.9% oxygen cylinder, remove the multi-meter, install the cover back on the transmitter housing.

5.3.10 Push the reset button located on the bottom of the controller housing. This will return the unit to normal operation.

5.3.11 Re-test for alarm activation conditions to insure that the unit is in full normal operation condition; see section 2.2.4 thru 2.2.7.

5.3.12 Notify the Control Room that the calibration is complete and the monitor is returned to normal service.

5.3.13 Record all findings on the “NSLS: O_2 Monitor Quarterly Preventive Maintenance (Calibration) Schedule.

5.4 Quarterly Calibration for GASTECH Safe T Net 210.

5.4.1 Notify the Control Room that the unit is being calibrated and all related alarms will be activated.

5.4.2 Verify that the unit is reading normal oxygen levels (20.9%) and that all indications and automatic functions are in a normal state.

5.4.3 Unscrew the cover from the transmitter housing.

5.4.4 Set the multi-meter to read in a range of 100 to 500 mV DC and connect the positive lead to the white test jack and the negative lead to the blue test jack located inside of the transmitter.

5.4.5 Connect the 100% nitrogen cylinder to the sensor housing using the supplied connection cup and hose. Open the cylinder valve slowly (ideally adjust it to a 1.0 SCFH flow rate, if a flow meter is available).

5.4.6 Observe the reading on the multi-meter and on the display screen. The multi meter should read 100 mV DC to correspond with the display reading of 0.0%. If necessary adjust the "Zero" potentiometer located inside of the transmitter so that the display reads 0.00%. (Clockwise increases, Counter-clockwise decreases).

5.4.7 Close the valve and remove the 100% nitrogen cylinder from the sensor housing.

5.4.8 Connect the 20.9% oxygen cylinder to the sensor housing; open the cylinder valve slowly (ideally adjust it to a 1.0 SCFH flow rate if a flow meter is available). If necessary, adjust the "Span" potentiometer located inside of the transmitter housing to 379 mV, which corresponds to 20.9%. (Clockwise increases, Counter-clockwise Decreases)

5.4.9 Close and remove the 20.9% oxygen cylinder, remove the multi-meter, install the cover back on the transmitter housing.

5.4.10 Repeat 4.5 through 4.9 for the second transmitter.

5.4.11 Push the reset button located on the bottom the controller housing. This will return the unit to normal operation.

5.4.12 Retest for alarm activation conditions to insure unit is in full normal operation condition; see section 2.2.4 thru 2.2.7.

5.4.13 Notify the Control Room that the calibration is complete and the monitor is returned to normal service.

5.4.14 Record all findings on the "NSLS: O_2 Monitor Quarterly Preventive Maintenance (Calibration) Schedule.

5.5 MANDATORY ANNUAL SENSOR REPLACEMENT

5.5.1 Notify the Control Room that the unit is being calibrated and all related alarms will be activated.

5.5.2 Observe and record the original oxygen level reading.

5.5.3 Unscrew the sensor cover by holding the mating part with a wrench.

5.5.4 Remove old sensor by slowly unplugging it from its socket.

5.5.5 Install the new sensor and plug the pins to position the sensor in the center of sensor's housing.

5.5.6 Perform steps 4.3 through 4.12

5.5.7 Perform functional test and complete the form according to the steps described in the attachment to this procedure.

5.5.8 **<u>Upon replacing any sensor, the interlocks connected to that sensor must be recertified.</u>**

5.5.9 Notify the Control Room that the annual maintenance is complete and the monitor is returned to normal service.

6.0 INTERLOCK TESTING

Each designated ODH area interlock alarm system shall be tested annually according to the steps described in the attachment to this procedure. If responses to any prescribed steps during this test or repair are "NO", then authorized person shall initiate immediate repair.

7.0 RECORDS

7.1 Completed weekly and monthly checklists are kept near each sensor controller.

7.2 Completed quarterly and annual checklists are kept by the NSLS QA manager.

NSLS: O_2 Monitor ***Weekly*** Preventive Maintenance Schedule

Room # _______________ **Unit Serial #** _________ **Safe T Net #** ______________ **Year** __________

WEEK	DATE	NAME	PILOT LIGHT ON?		% O_2	COMMENTS/ ADJUSTMENTS
			Yes	No*		
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						

NSLS: O_2 Monitor ***Monthly*** Preventive Maintenance Schedule

Room # _______________ Unit Serial # _________ Safe T Net # ______________ Year __________

Control Room Notified? Yes ☐ No ☐ If no, do not proceed.

Date	Name	**PILOT LIGHT**		**O_2 % PRE-TEST READS**	**O_2 % DECREASES WHEN BREATHING ON SENSOR HEAD**		**ALARM AND AUTOMATIC ACTIONS ACTIVATE?**		**ALARM RESET TO NORMAL % O_2?**	
		ON	OFF		YES	NO	YES	NO	YES	No
Jan/										
Feb/										
Mar/										
Apr/										
May/										
Jun/										
Jul/										
Aug/										
Sep/										
Oct/										
Nov/										
Dec/										

NSLS: O_2 MONITOR, ***<u>Quarterly</u>*** CALIBRATION SCHEDULE

M&TE #____________Unit Serial # _______________ Room #______________________

Date: __________________ **Technician:** ________________________________

Follow procedures described in sections 3 and 4 to complete this form.

Control Room Notified? Yes ☐ No ☐

Was a new sensor required? Yes ☐ No ☐

Using 100% N_2 Cylinder, Monitor Reading _____% O_2 Zero Pot Reads _______ mV

Using 20.9% O_2 Cylinder Monitor Reading _____% O_2 Scan Pot Reads________mv

Warn Trip set point __________ % O_2

Alarm Trip set point __________ % O2

Automatic Actions Activate Yes ☐ No ☐

Control Room Alarm trip? Yes ☐ No ☐

O_2% Post Test Reads __________ % O_2

Pass Test? Yes ☐ No☐

If no, contact responsible system engineer to resolve the problem. Notify the Control Room that the scheduled maintenance is complete and the monitor is returned to normal service.

NSLS: O_2 Monitor, ***Annual*** maintenance Schedule

M&TE #____________Unit Serial # _______________ Room #______________________

Date: __________________ **Technician:** ________________________________

Control Room Notified? Yes ☐ No ☐

Sensor Replaced? Yes ☐ No ☐

Using 100% N_2 Cylinder, Monitor Reading _____% O_2 Zero Pot Reads ______ mV

Using 20.9% O_2 Cylinder Monitor Reading _____% O_2 Scan Pot Reads_______mv

Warn Trip set point __________ % O_2

Alarm Trip set point __________ % O2

Automatic Actions Activate Yes ☐ No ☐

Control Room Alarm trip? Yes ☐ No ☐

O_2% Post Test Reads __________ % O_2

Perform interlock functional test and complete appropriate forms dictated in this procedure.

Pass all functional tests? Yes ☐ No☐

If no, contact the interlock engineer to resolve the problem. Notify the Control Room that the annual maintenance is complete and the monitor is returned to normal service.

ODH Alarm system, Functional tests

West Roll Up Door Area Room 151A

The following will test the operation of the ODH alarm system and signaling components in the West roll up door area. <u>This is not a calibration procedure for the ODH sensors or monitor box.</u>

In a safe manner consistent with NSLS operating procedures open the nitrogen fill valve and verify it is open.

Nitrogen fill valve open	Yes ☐	No ☐

1. Create an OHD alarm and observe the following:

The audible alarm on the O2 sensor box sounds.	Yes ☐	No ☐
The audible alarm mounted on the wall sounds.	Yes ☐	No ☐
The outdoor sign lights (ramp).	Yes ☐	No ☐
The indoor beacon lights. (Between roll up doors)	Yes ☐	No ☐
The experimental area beacon lights	Yes ☐	No ☐
The ramp roll up door opens.	Yes ☐	No ☐
The control room reports (WEST ROLL UP DOOR ODH" alarms)	Yes ☐	No ☐
The Nitrogen fill valve closes.	Yes ☐	No ☐

2. Reset the ODH alarm.

In a safe manner consistent with NSLS operating procedures open the nitrogen fill valve and verify it is open.

Nitrogen fill valve open	Yes ☐	No ☐

3. Shut off the AC power to the system and observe the following:

The control room reports "WEST ROLL UP DOOR ODH SYSTEM TROUBLE"

The nitrogen fill valve closes.	Yes ☐	No ☐
The Nitrogen fill valve cannot be opened.	Yes ☐	No ☐

The Yellow led in the battery backup is on and the Green led is off.

Yellow Led ON	Yes ☐	No ☐
Green Led OFF	Yes ☐	No ☐

4. Create an ODH alarm and observe the following:

The audible alarm on the O2 sensor box sounds.	Yes ☐	No ☐
The control room reports "MER A ODH" alarm	Yes ☐	No ☐

5. Restore the AC power and confirm that the green led in the battery back up unit is on. This indicates normal operation.

Green Led ON	Yes ☐	No ☐
Yellow Led OFF	Yes ☐	No ☐

6. All control room alarms are normal. Yes ☐ No ☐

In a safe manner consistent with NSLS operating procedures open the nitrogen fill valve and verify it is open.

Nitrogen fill valve open	Yes ☐	No ☐

7. Shut off the power to the roll up door opener and observe:

The control room reports **"WEST ROLL UP DOOR ODH SYSTEM TROUBLE"**

The Nitrogen fill valve closes and cannot be opened.	Yes ☐	No ☐
The Trouble light is ON	Yes ☐	No ☐

8. Restore roll up door AC power and observe normal operation.

The trouble light is OFF	Yes ☐	No ☐

9. All control room alarms are normal. Yes ☐ No ☐

Note: If responses to any prescribed steps during this test or repair are "NO", then authorized person shall initiate immediate repair.

ODH Alarm system, Functional tests

LEGS CRYO AREA Room 169

The following will test the operation of the ODH alarm system and signaling components in the LEGS Cryo area. <u>This is not a calibration procedure for the ODH sensors or monitor box.</u>

1. Create a OHD alarm and observe the following:

The audible alarm on the O2 sensor box sounds.	Yes ☐	No ☐
The audible alarm mounted on the wall sounds.	Yes ☐	No ☐
The outdoor beacon lights.	Yes ☐	No ☐
The indoor beacon lights.	Yes ☐	No ☐
The control room reports “X5 CRYO ODH” alarm	Yes ☐	No ☐

2. Reset the ODH alarm.

3. Shut off the AC power to the system and observe the following:

The control room reports X5 CRYO ODH SYSTEM TROUBLE”	Yes ☐	No ☐

The Yellow led in the battery backup is on and the Green led is off.

Yellow Led ON	Yes ☐	No ☐
Green Led OFF	Yes ☐	No ☐

4. Create an ODH alarm and observe the following:

The audible alarm on the O2 sensor box sounds.	Yes ☐	No ☐
The audible alarm mounted on the wall sounds.	Yes ☐	No ☐
The outdoor beacon lights.	Yes ☐	No ☐
The indoor beacon lights.	Yes ☐	No ☐
The control room reports “X5 CRYO ODH” alarm	Yes ☐	No ☐

5. Restore the AC power and confirm that the green led in the battery back up unit is on. This indicates normal operation.

Green Led ON	Yes ☐	No ☐
Yellow Led OFF	Yes ☐	No ☐

6. All control room alarms are normal. Yes ☐ No ☐

Note: If responses to any prescribed steps during this test or repair are “NO”, then authorized person shall initiate immediate repair.

ODH Alarm system, Functional tests

Mechanical Equipment Room A (MER A) Room 210

The following will test the operation of the ODH alarm system and signaling components in MER A. <u>This is not a calibration procedure for the ODH sensors or monitor box.</u>

1. Create a OHD alarm and observe the following:

The audible alarm on the O2 sensor box sounds.	Yes ☐	No ☐
The audible alarm mounted on the wall sounds.	Yes ☐	No ☐
The outdoor beacon lights.	Yes ☐	No ☐
The indoor beacon lights.	Yes ☐	No ☐
The exhaust fan operates.	Yes ☐	No ☐
The control room reports “MER A ODH” alarm	Yes ☐	No ☐

2. Reset the ODH alarm.

3. Shut off the AC power to the system and observe the following:
   The control room reports “MER A ODH SYSTEM TROUBLE”

   Yes ☐ No ☐

   The Yellow led in the battery backup is on and the Green led is off.

Yellow Led ON	Yes ☐	No ☐
Green Led OFF	Yes ☐	No ☐

4. Create an ODH alarm and observe that the system functions on the battery power as in step 1.

The audible alarm on the O2 sensor box sounds.	Yes ☐	No ☐
The audible alarm mounted on the wall sounds.	Yes ☐	No ☐
The outdoor beacon lights.	Yes ☐	No ☐
The indoor beacon lights.	Yes ☐	No ☐
The exhaust fan operates.	Yes ☐	No ☐
The control room reports “MER A ODH” alarm	Yes ☐	No ☐

5. Restore the AC power and confirm that the green led in the battery back up unit is on. This indicates normal operation.

Green Led ON	Yes ☐	No ☐
Yellow Led OFF	Yes ☐	No ☐

6. All control room alarms are normal. Yes ☐ No ☐

Note: If responses to any prescribed steps during this test or repair are “NO”, then authorized person shall initiate immediate repair.

(X17 LHe Dewar Relief Size, Using ASME Code (Ref, Cryogenic Systems 2nd Edition by Randall F. Barron)

Volume = 1.00E+06 cc

Heat Leak= 3370.0 Watts (0.0583 watts/Sq cm, total surface area ~ 57806 Sq. cm)

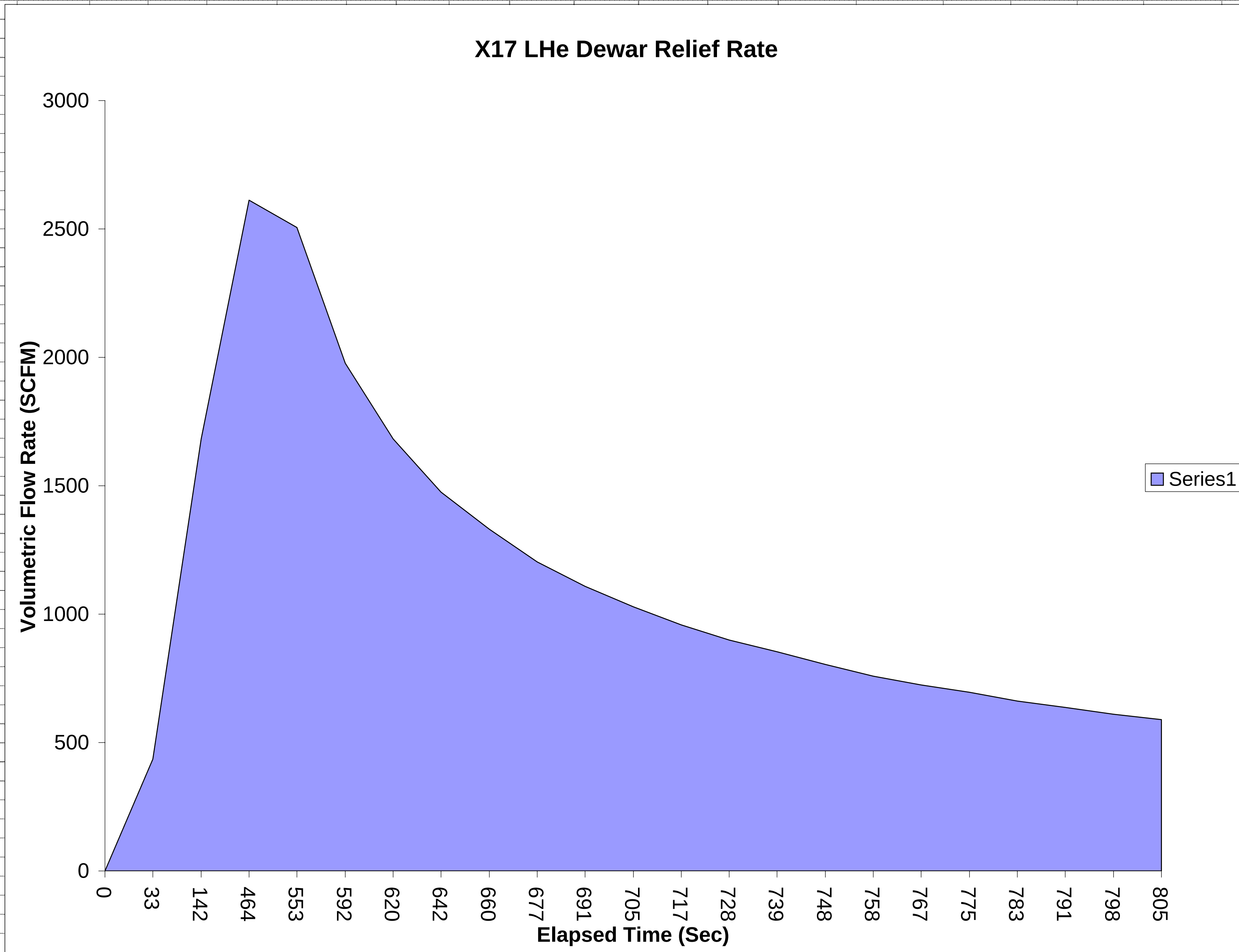
Pres. (bara)	Temp. (K)	Density (g/cc)	Enthalpy (J/g)	Internal Energy (J/g)	Mass (g)	Energy Change (J)	Time (Sec)	Elapse Time (Sec)	Mass Flow Rate (g/s)	Helium Left Per Cent	Volume Flow Rate SCFM	Universal He Gas Cor J/mol- K	Ratio of Spec Heat (Unitless)	ASME Code "C" Factor (Unitless)	Discharge Pres.(Pmax) Pasc (N/m^2)	Discharge Coeff, K_D (unitless)	Discharge Area In^2	Relief Diameter (in)
1.6	4.20	1.288E-01	10.02	8.780	1.29E+05	0.00E+00	0.00	0.00	0.0	100.00%	0	8.3144	1.660	0.725	165804.895	0.750	0.000000	0.000
2.6	4.50	1.277E-01	11.680	9.648	1.28E+05	1.11E+05	32.89	32.89	33.4	99.15%	436	8.3144	1.660	0.725	275766.977	0.750	0.004228	0.073
2.6	5.00	1.136E-01	14.740	12.450	1.14E+05	3.69E+05	109.36	142.25	128.9	88.20%	1682	8.3144	1.660	0.725	275766.977	0.750	0.017181	0.148
2.6	5.50	4.910E-02	28.080	22.780	4.91E+04	1.09E+06	321.99	464.24	200.3	38.12%	2613	8.3144	1.660	0.750	275766.977	0.750	0.027071	0.186
2.6	6.00	3.196E-02	35.490	27.360	3.20E+04	3.01E+05	89.24	553.48	192.1	24.81%	2506	8.3144	1.660	0.725	275766.977	0.750	0.028038	0.189
2.6	6.50	2.608E-02	40.000	30.030	2.61E+04	1.31E+05	38.78	592.26	151.6	20.25%	1978	8.3144	1.660	0.725	275766.977	0.750	0.023035	0.171
2.6	7.00	2.254E-02	43.810	32.270	2.25E+04	9.25E+04	27.46	619.72	128.9	17.50%	1682	8.3144	1.660	0.725	275766.977	0.750	0.020329	0.161
2.6	7.50	2.005E-02	47.290	34.320	2.01E+04	7.42E+04	22.01	641.73	113.1	15.57%	1476	8.3144	1.660	0.725	275766.977	0.750	0.018464	0.153
2.6	8.00	1.815E-02	50.570	36.250	1.82E+04	6.28E+04	18.63	660.36	102.0	14.09%	1330	8.3144	1.660	0.725	275766.977	0.750	0.017189	0.148
2.6	8.50	1.665E-02	53.730	38.110	1.67E+04	5.48E+04	16.27	676.62	92.2	12.93%	1203	8.3144	1.660	0.725	275766.977	0.750	0.016021	0.143
2.6	9.00	1.541E-02	56.800	39.920	1.54E+04	4.92E+04	14.59	691.21	85.0	11.96%	1109	8.3144	1.660	0.725	275766.977	0.750	0.015196	0.139
2.6	9.50	1.436E-02	59.800	41.700	1.44E+04	4.49E+04	13.31	704.52	78.9	11.15%	1029	8.3144	1.660	0.725	275766.977	0.750	0.014488	0.136
2.6	10.00	1.347E-02	62.750	43.440	1.35E+04	4.09E+04	12.12	716.65	73.4	10.46%	958	8.3144	1.660	0.725	275766.977	0.750	0.013833	0.133
2.6	10.50	1.269E-02	65.660	45.170	1.27E+04	3.82E+04	11.32	727.97	68.9	9.85%	899	8.3144	1.660	0.725	275766.977	0.750	0.013305	0.130
2.6	11.00	1.200E-02	68.530	46.870	1.20E+04	3.55E+04	10.54	738.51	65.4	9.32%	854	8.3144	1.660	0.725	275766.977	0.750	0.012936	0.128
2.6	11.50	1.139E-02	71.380	48.560	1.14E+04	3.33E+04	9.89	748.40	61.7	8.84%	805	8.3144	1.660	0.725	275766.977	0.750	0.012464	0.126
2.6	12.00	1.085E-02	74.200	50.240	1.09E+04	3.13E+04	9.29	757.69	58.1	8.42%	758	8.3144	1.660	0.725	275766.977	0.750	0.011998	0.124
2.6	12.50	1.036E-02	77.010	51.910	1.04E+04	2.97E+04	8.82	766.52	55.5	8.04%	725	8.3144	1.660	0.725	275766.977	0.750	0.011703	0.122
2.6	13.00	9.914E-03	79.790	53.560	9.91E+03	2.82E+04	8.36	774.88	53.4	7.70%	696	8.3144	1.660	0.725	275766.977	0.750	0.011463	0.121
2.6	13.50	9.508E-03	82.560	55.220	9.51E+03	2.70E+04	8.01	782.89	50.7	7.38%	661	8.3144	1.660	0.725	275766.977	0.750	0.011098	0.119
2.6	14.00	9.136E-03	85.320	56.860	9.14E+03	2.57E+04	7.62	790.50	48.8	7.09%	637	8.3144	1.660	0.725	275766.977	0.750	0.010891	0.118
2.6	14.50	8.794E-03	88.060	58.500	8.79E+03	2.46E+04	7.31	797.81	46.8	6.83%	611	8.3144	1.660	0.725	275766.977	0.750	0.010621	0.116
2.6	15.00	8.478E-03	90.800	60.130	8.48E+03	2.36E+04	7.00	804.81	45.1	6.58%	589	8.3144	1.660	0.725	275766.977	0.750	0.010418	0.115

$A_v = m_g (R_u T/g_c M)^{1/2}/CK_D p_{max}$ (eq. 7.24) A_v = discharge area of valve

p_{max} = (set gauge pressure)(1.10) + (atmospheric pressure) m_g = max. mass flow rate

$C = [gama(2/(gama+1))^{(gama+1)/(gama-1)}]^{1/2}$ gama = c_p/c_v Specific heat ratio

K_D = dischage Coefficient determined by test (assumed 0.75 in this calculatation)


X17 LHe Dewar Relief Rate
Volumetric Flow Rate (SCFM)
3000
2500
2000
1500
1000
500
0
0
33
142
464
553
592
620
642
660
677
691
705
717
728
739
748
758
767
775
783
791
798
805
Elapsed Time (Sec)
Series1

X17 LHe DEWAR RELIEF SYSTEM

Background

In the event of a casualty such as loss of cryostat Insulating vacuum, provision must be made to allow for the safe discharge of gaseous helium in excess of the normal boil-off from the liquid He vessel. This is done by having spring loaded relief valves attached to the helium vent line which when tripped will allow the gas to vent through a suitably sized line to the outside. Paul-Hoffman Cryogenic Division, a company no longer in business, manufactured the X17 LHe Dewar in 1966. The Dewar is equipped with two relief valves, a ¼" Circle Seal valve set at 15 psig (30 psia) serving as primary relief venting to the outside and an unused in-line ½" size (apparently used during initial liquefaction to reduce Dewar pressure).. The purpose of this calculation was to examine the adequacy of the manufacturer's provided relief valve that was found to be inadequate. As a result, another ½" Kunkle RV set at 25 psig (40 psia) serving for high flow rate in case of loss of vacuum was added. This higher set value is deliberately selected (within safe inner vessels's tested design pressure) since valve does not re-seal itself until 15 psig. The combination of these two relief valves provided adequate relief as shown on the attached spreadsheet. Furthermore, two redundant ½" burst disks set at 34 psig (well below MAWP of 40 psig of the Dewar) have also been added as another safety feature. The purpose of this redundancy is to be able safely to switch from one burst disk (in case of failure) to the second one without loss of operation time by following an established procedure. The reasons for selecting these relief pressure values are described later in this note.

CALCULATE HEAT LEAK

Estimating the heat load from such an occurrence is done using a graph (figure 6.3) from the NBS Monograph 111 "Technology Of Liquid Helium" . This graph plots heat flux vs. liquid container area for multilayer insulated liquid helium containers under various casualty conditions and insulation thicknesses.

SAFE AND EFFICIENT USE OF LIQUID HELIUM

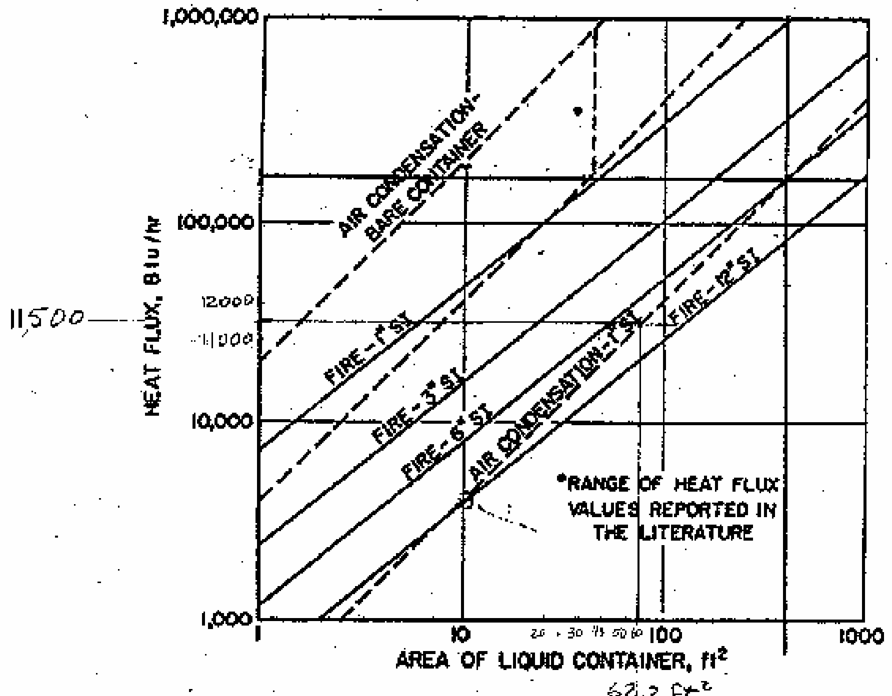


Figure 6.3. *Estimated total heat flux versus area for air condensation and fire conditions in multilayer (SI) insulated liquid helium containers.*

The LHe container’s physical dimension and amount of insulation are estimated values. The vacuum vessel measured dimensions are:

Outer Tank; (Circumference 173” X 48” H)

OD = 173”/p = 55 in

Assuming 4” Space between inner and pouter tank, then:

Estimated Inner Tank’s Dimension:

ID = 55 – 9 = 46 in
H = 48 – 9 = 39 in

This results in a surface area of: $A = 2\Pi (D/2)^2 + \Pi D L$

$$A = 2\Pi(23)^2 + \Pi(46)(39) = 8960 \text{ in}^2 = 62.2 \text{ ft}^2 = 57806 \text{ cm}^2$$

Therefore, corresponding total heat rate for such surface area assuming covered with one inch thick Super-Insulation from graph is 11000 BTU/hr or:

11,500 BTU/Hr X Watts/ (3.412Btu/hr)= 3370 Watts

Resulting in heat flux of q = 3370 Watts/57806 cm^2 =0.0583 Watts/cm^2
The nominal volume of helium in the vessel is 1000 liters.

CALCULATE GAS FLOW

The helium gas mass flows and total relief valves throat area are calculated using a spreadsheet program. The program determines the mass flow with time for a constant heat load. An ASME relief valve sizing equation is used to calculate the required valve throat area. This sizing equation is also recommended by the Compressed Gas Association pamphlet "Safety Relief Valve Standards" (Pamphlet S-1, Parts 2 & 3) as well as Anderson, Greenwood and Co., a relief valve manufacturer.

The assumptions for the calculation are:

1. The Cold Mass of the Dewar is conservatively assumed to have no effect on the heating of the helium in the vessel.

2. The heat load is 3370 Watts.

3. The heat load is initially applied at the system operating conditions of P = 21 psia (1.4 ATM, 1.6 bar) and T = 4.2 K.

4. There are two relief valves venting to atmosphere. An originally installed ¼" Circle Seal valve set at 15 psig (30 psia) serving as control (since it re-seats closer to the set point) and an added ½" Kunkle RV set at 25 psig (40 psia) serving for high flow rate in case of loss of vacuum. This higher set value is deliberately selected (within safe inner vessel's tested design pressure) since valve does not re-seal itself until 15 psig. The following calculation is performed for a worst-case condition (i.e. loss of vacuum) in which both relief valves will fully open. When the relief valves open, the pressure is assumed to rise to a 2.6 bar (25psig + 10% for fully open + 14.7 = 42.2 psia = 2.871 atm) with the venting process continuing at constant pressure and increasing temperature.

The following ASME Code formula (7.24) from Cryogenic Systems by Randall F. Barron has been used to determine the required size of the safety relief valve.

$$A_v = m_g \, (R_u T/g_c M)^{1/2}/CK_D p_{max} \qquad \text{Eq. 7.24 (Randall)}$$

Where: A_v = discharge area of val1ve

m_g = maximum mass flow rate through valve

R_u = Universal gas constant

T = absolute temperature of the gas at the inlet to the valve

M = molecular weight of gas flowing through the valve

g_c = unit cvonversion factor in Newton's Second Law = 1 kg-m/N-S^2

K_D = discharge coefficient determined by test

P_{max} = (set gauge pressure)(1.10) + (atmospheric pressure)

$$C=[\gamma(2/(\gamma+1))^{(\gamma+1)(\gamma-)}]^{1/2}$$

$\gamma = c_p/c_v$ = specific heat ratio of gas

The entries and formulas in the spreadsheet calculation are as follows:

Columns 1, assigned Pressure of 1.6 bar and 2.6 bar absolute corresponds to ¼" Circle Seal and ½"Kunkle relief valves set points respectively.

Column 2, Assigned temperatures

Columns 3, 4 and 5: (density, enthalpy and internal energy) are obtained from the NBS Tables for Helium.

Column 6, Mass of He is calculated from the formula:

$M_c = D_c$ X (Dewar Volume) Where: M_c = He mass at current data pt, g

D_c = He density at current data pt

Dewar Volume = 1000,000 cc

Column 7, He Energy Change is given by the formula:

$$E_c = U_cM_c - U_pM_p + [(h_c + h_p)/2]\,[M_p - M_c]$$

Where: E_c = He energy change at current data pt, J

U_c = He internal energy at current data pt, J/g

U_p = He internal energy at previous data pt, J/g

M_p = He mass at previous data pt, g

h_c = He enthalpy at current data pt, J/g

h_p = He enthalpy at previous data pt, J/g

Column 8, Time required for energy change is calculated from:

$t_c = E_c / Q$ Where: t_c = time at current data pt, sec

Q= Heat leak = 3370 Watts

Column 9, Elapsed Time is calculated from:

$ET_c = ET_p + t_c$ Where: ET_c = elapsed time at current data point, sec
ET_p = elapsed time at previous data point, sec
t_c = time at current data point, sec

Column 10, Mass Flow is calculated from:

$MF_c = [M_p - M_c]/ t_c$ Where: MF_c = Mass flow of He, g/sec

Column 11, Helium left in percent is from:

$H\% = M_c$ /Original He mass

Column 12, Volume Flow is calculated from:

$V_f = MF_c$ (60 sec / 1 min.) (1 lbm/ 453.6 g) (1 ft^3/ 0.01014 lbm)

Where: V_f = He volume flow, SCFM

Column 13, Universal gas constant in MKS system, 8.3144 J $moles^{-1}$ K^{-1}
REF. http://scienceworld.olfram.com/physics/UniversalGasConstasnt.html)

Column 14, Ratio of specific heat for helium, 1.66
(REF. http://sciencetoolbox.com/specific-heat-ratio-21_608.html)

Column 15, Calculated "C" factor (see equation 7.24)

Column 16, discharge pressure [column1*14.5psi/bar – 14.7)(1.10) + 14.7]*1Pascal/ 1.4505E –04 = N/m^2

Column 17, Discharge Coefficient Pressure, assumed 0.75

Column 18, Calculated from equation 7.24 in m^2 converted to in^2 by multiplication factor of (1550 in2/m2)

Column 19, Valve ID is from:

$ID = (4\ K\ A/ \Pi)^{1/2}$ Where: ID = inside diameter, in

Conclusion: The discharge coefficient factor greatly affects the final results. While, a realistic value can only be obtained by performing test under actual relief boundary condition, a value of 0.75 was assumed in this calculation based on an engineering judgment and the verbal discussion with a Circle Seal engineer. However, examined relief diameters of 0.227" to 0.161" which corresponds to discharge factors of 0.5 to 1 turned out to fall well within sum of two relief diameters of ¼" (supplied by manufacturer) and a ½" Kunkle type later on added as a result of this finding. The Kunkle relief valve while has poor re-sealing performance, it provides high flow rate in a catastrophic situation. In addition, two redundant ½" burst disks set at 34 psig (well below MAWP of 40 psig of the Dewar) have also been added as another safety device. Furthermore, relieved helium gas is piped to the outside building, which greatly reduces the chance of ODH condition.

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